

SUSTAINABLE STRATEGIES FOR URBAN WATER MANAGEMENT FOR ARID
REGION: THE CASE STUDY OF JEDDAH CITY SAUDI ARABIA

BY

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THESIS

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ABSTRACT

With the global concern of climate change, particularly the water shortage and degradation of the urban environment in Middle East and North Africa (MENA), there is a need for sustainable strategies to overcome these problems. This research studies the traditional and modern practices of rainwater harvesting and storm water management to provide sustainable strategies for urban water management in arid regions, using Jeddah City in Saudi Arabia and its historical urban core as a case study. The research methods and results are established with quantitative and qualitative data.

Jeddah suffers from a lack of water (excessive aridity), but also suffers sporadic floods (excessive water). Rainwater collection and harvesting is a strategy that can address both conditions of excess. A model that relies on three metrics is suggested to study the possibility of urban rainwater harvesting in Jeddah City. These include measuring the potential rainwater harvesting volume, the water requirement for a landscape area, and the volume of rooftop rainwater available for capture in the historical city of Jeddah. Results indicate that a substantial amount of preserved rainwater can be captured and used for landscape purposes in the study area.

The design strategy proposes implementation in two phases. The first is a strategy to collect rainwater from rooftops in the historical area and to store it in neighborhood storage tanks located in selected public spaces, in addition to a green network plan to manage the storm water runoff. The second phase focuses on an urban transect that intended to analyze the urban fabric for the historical and the modern Jeddah City. A set

of sustainable water management strategies is selected for three main urban typologies:
buildings, streets, and parking lots with respect of their distinct zone location.

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CHAPTER 1

INTRODUCTION

Today, climate change holds unprecedented challenges for the entire planet's ecosystem. Imbalanced interactions arise between the need for development, increasing population, and the environment, which contributes to the negative impact of climate change. Most of world's nations face urgent global concerns regarding climate change, but each region faces them differently due to various reasons including disparity in geographic characteristics, economic development, and access to resources. The arid regions of the Middle East and North Africa (hereafter referred to as MENA nations and defined as Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Tunisia, the United Arab Emirates, and Yemen) suffer most from declining per capita water resources, degradation of the urban environment, and the absence of appropriate environmental institutions and legal frameworks.¹

Water is an essential resource for our lives. Throughout history, many civilizations flourished in the modern-day MENA region where water is extremely limited. According to a United Nations the human development report on the Arab states, the rainfall distribution is highly variable among MENA nations; “around 52% of the region's area receives an average annual rainfall of less than 100 mm, while 15% receives 100 – 300 mm and 18% receives more than 300 mm.”² Based on the same report, there are some countries—such as Syria and Lebanon—that receive a maximum rainfall of 1500mm/year. However, a large amount of the rainfall is lost due to surface

runoff and evaporation. Saudi Arabia is among the driest of the MENA nations with an average annual precipitation ranging from 80-140 mm/year, except for the southwestern province of Asir, which receives an average of 300mm/year.³

In the last five decades, many MENA nations have experienced substantial urban development due to the oil boom. In total, their urban populations have expanded from 231 million in 1995 to 339.6 million in 2012.⁴ In these countries, the rapid urbanization, development, and lack of natural and planned green spaces affect the natural landscape, leading to environmental degradation. In addition, the water demand dramatically increases due to rapid population growth, inefficient use of water for irrigation, and new industrial requirements.

Historically, people of the MENA region have developed numerous technical solutions—such as rainwater harvesting—to deal with many environmental constraints and particularly the water scarcity problem. Unfortunately, in the modern era, many traditional practices for water management and environmental control have been abandoned in favor of modern practices that are not fully based on sustainable solutions. As the water crisis becomes more critical, there is need for new sustainable solutions and strategies to meet the current and increasing human needs in order to not only recover the damaged environment, but also sustain it for the future.

At the present time, many MENA regions' cities are facing various environmental challenges due to climate change, population growth, and urban development. Among those most vulnerable is Jeddah City in Saudi Arabia. Jeddah City is an important center for economic, social, cultural, and political activities with a rich history that is currently experiencing significant degradation of the environment and natural resource. Jeddah

City suffers from excessive aridity, but also suffers excessive water that is caused by sporadic floods. Rainwater collection and harvesting is a strategy that can be used in the historical city of Jeddah to address both conditions of excess. Unfortunately, the practice of rainwater harvesting was not included during the new development and eventually was also abandoned within the historical city. Today, Jeddah City needs solutions to address its current water and environmental problems. One of the areas in Jeddah City that requires urgent solutions is its historical core.

This thesis proposes that a sustainable water management strategy can be developed for urban areas in Jeddah City using both traditional knowledge as well as the modern practice of rainwater harvesting. Considering the historical importance, as well as urgent needs, I have chosen the historical city of Jeddah as my sample site to illustrate the proposed sustainable water management strategies. The objective of this work is: (1) to provide sustainable water recourse for drinking and irrigation, (2) to minimize the consumption of non-renewable natural resources, (3) to minimize urban runoff by using soft infrastructure solutions such as Green Infrastructure, and (4) to upgrade and improve the environmental quality and social life of the growing population. The research methods for this project include both quantitative and qualitative data collection methods.

1.1 Conceptual Framework

This study begins with presenting the current urgent concerns among the MENA nations and particularly in Jeddah City. Chapter 2 provides a historical overview of the development of rainwater harvesting techniques and practices in Jeddah City. In this chapter, I explain that the cultural heritage value of rainwater harvesting and its

importance in developing Jeddah City. In addition, this chapter also features the current key water-related concerns in the city: urbanization, population growth, tourism growth, climate change, and lack of green public spaces. Chapter 3 contains a literature review of rainwater harvesting, Green Infrastructure, storm water management design strategies and the barriers that impede the implementation of these techniques. Chapter 4 includes a quantitative research study that informs my general assessment for the feasibility of rainwater harvesting in residential urban settings in Jeddah City. Chapter 5 proposes sustainable rainwater harvesting and storm water management strategies for the historical city of Jeddah. The design strategy proposes implementation in two phases. The first is a strategy to collect rainwater from rooftops and store it in central storage tanks for later use. The second phase focuses on an urban transect that is useful for analyzing the urban fabric for both the historical and the modern Jeddah City. A set of sustainable water management strategies is selected for three critically important urban typologies, namely buildings, streets, and parking lots in the historical city of Jeddah and its surrounding area. The proposed solutions are based on rainwater harvesting techniques in conjunction with other sustainable related approaches. The final chapter concludes this thesis research with a summary and offers some conclusions and recommendations.

1.2 Research Significance

Due to the escalating problems of climate change, water shortage, and degradation of the urban environment in most MENA regions and particularly in Jeddah City, the existing planning and design strategies are unsustainable. However, the traditional methods of rainwater harvesting coupled with Green Infrastructure could

support sustainable development. They would provide an additional water supply through better catchment and introduce new green open spaces that would help improve environmental quality, public health, and enhance the image of the city. Therefore, this thesis proposes sustainable solutions and strategies for Jeddah City to deal with its current water and environmental challenges. Applying the proposed sustainable solutions to the historical city of Jeddah will further enhance and maintain its unique cultural heritage and thus improve its chances of being inscribed on the UNESCO World Heritage list.

CHAPTER 2

JEDDAH CITY INVENTORY

This chapter explores the history of water development in Jeddah City in the past three millennia, focusing on the key water-related concerns in the city regarding urbanization, population growth, tourism growth, climate change and lack of green public spaces today.

2.1 History of Water Development in Jeddah City

The city of Jeddah is a Saudi Arabian seaport located on the eastern shore of the Red Sea (29.21° N and 39.7° E) (see Figure 1). It is surrounded from the east with the plains of Tihama and from the west along the coast there are a series of coral reefs. Jeddah has a semi-tropical climate, with high temperatures and humidity during the summer seasons and mild temperature and low humidity in winters.⁵ The average monthly temperatures range from 14°C during the winter to 43°C during summer months. The average annual precipitation is approximately 53.5 mm.



Figure 1 Location of Jeddah City, Saudi Arabia (Source: Reproduced by the author from the UNESCO nomination document for the historical city of Jeddah)

Jeddah was first inhabited in the 2nd century BCE as a small fishing settlement and has long been a center for traders and sailors.⁶ According to many Arab and Muslim writers, the name “Jeddah” was derived from the Arabic word for “Grandmother” in reference to Eve who, as folklore recounts, was buried in old Jeddah in a site known as the “Cemetery of Our Mother Eve.”⁷ A second explanation that it is the name of the grandson of Quda’a, the chieftain of the Arab tribe that migrated from the south in search of a homeland and was the first to settle the area. Quda’a is the second son of Ma’ad ibn Adnan, who is considered the 19th grandfather of Prophet Mohammed.⁸ A third explanation is that the name is rooted in the Arabic word “Judda,” which describes the part of land that is connected and directly adjacent to a body of water.⁹

Around the 6th century CE, Persians settled in the city. They left their mark on the planning of the city by building the first city wall, digging a moat around the city to protect it from floods and outside attacks, and developing the harbor as an important trading center. More importantly, they constructed the first water supply system in the form of wells and cisterns inside and outside the city wall to secure enough continuous fresh water.¹⁰

The city gradually developed into one of the more important stations along a trade route that connected the civilizations of the Mediterranean to the East. During the 7th century CE, Jeddah’s importance grew during the reign of the third Muslim caliph, Uthman ibn Affan (644-56 CE) who wisely decided to transform Jeddah into the main port for Makkah (Mecca). Since then, Jeddah has become the main gateway to the two most important Muslim Holy Cities, Makkah and Madinah,¹¹ and thus the destination for the millions of local and foreign Muslim pilgrims who visit for the annual pilgrimage

every year; in 2011 their number exceeded 3 million.¹² Although this annual surge of visitors has given Jeddah an important symbolic meaning and boosted its economy, the pressure and the demand for water have dramatically increased because of the growing residential population and pilgrims.

The shortage of water is a historic condition that was documented by the famous traveler Ibn Battuta, who visited Jeddah City during the 14th century CE. He indicated in his travelogue that Jeddah City had a lot of connected water cisterns. However, he visited the city during the dry season and noticed that it took people one day to carry water from outside the city walls. In addition, he observed pilgrims asking for water from the local citizens because of the lack of a public water supply.¹³

By the mid-15th century CE, Jeddah City was under Ottoman rule. In 1566 CE the Ottoman Emperor Suleiman al-Kanuni, known as “the Magnificent,” ordered the formation of a professional committee to study the potential for bringing water to Jeddah City from the nearby village called Hedaa. From this, it is evident that the remaining water supply for the city was insufficient and an additional water supply was needed. Although ground water could easily be found everywhere in Jeddah City at a depth of fifteen feet, it typically had a salty or bad taste. Only a few wells on the southern side of the city contained drinkable water and these were accessible only by a few people. The rest of the population had to settle for the muddy water supplied by other wells.¹⁴

Unfortunately, the study commissioned by Sultan Suleiman showed many obstacles and critical problems in building a canal system. As a result, he ordered the digging of more cisterns instead the proposed canal system.¹⁵ Those cisterns resolved the situation and the city was able to harvest more rainwater, thus temporarily alleviating the

water problem. A century later, Mustafa Pasha—the Ottoman General and Grand Minister (Vizier) during the era of Sultan Mohammed IV—decided to permanently solve the water scarcity problem in Jeddah once and for all. He asked the Prince of Makkah, Sharef Saeed, to assign Kurd Ahmed al-Meamar—who was working on repairing the water system in Arafa, a site located in Makkah City—to build a new water system that would be sufficient for Jeddah City. However, since Kurd Ahmed was also assigned to work on multiple projects along with the earth canal project in Jeddah City, it is hard to determine exactly when he started working on the canal project and in which year the system was completed. Based on an inscription from Al-Gazi, we know that around a century after Suleiman’s initial plan, in 1683 CE, water was running from the Quz Valley to Jeddah through the canal system.¹⁶

During a period of three years, Kurd Ahmed was able to build a water canal system that started in the Quz Valley and continued to Jeddah City for a distance of 12 km (see Figure 2). Thus, during this period, Jeddah City had four techniques for harvesting rainwater: (1) the micro-catchment area called “Hofra” outside the city to collect water, (2) cisterns located inside and outside the city to harvest runoff rainwater, (3) wells that supply from groundwater, and (4) the canal system that captured spring water.

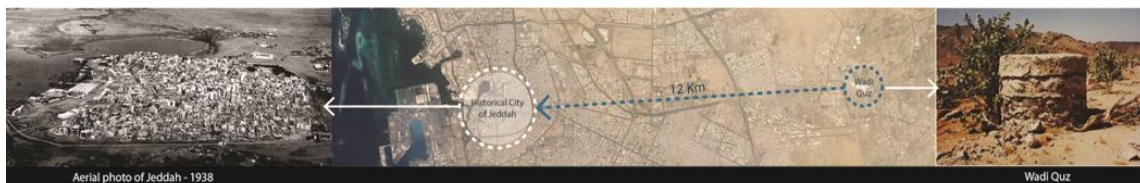


Figure 2 Location of Wadi Quz (Source of the images –Azhar, Jamal.1996. *Jeddah the gateway of the two holy mosques*. P284)

Unfortunately, in 1722 CE, the canal's water was disconnected from the city. One of the main reasons for the collapse of the system was the absence of regular maintenance. Native plants were attracted to the canal as a source of moisture, and their roots gradually caused damage to the canal structure. In addition, Arab Bedouin shepherds used the inspection holes along the canal to give water to their animals (who then frequently fell down those holes, blocking the water channels and contaminating them).¹⁷ Moreover, water commerce was a growing business in Jeddah City. Water dealers were anxious that the new public water system would negatively affect their business, and therefore they indirectly attempted to destroy the water system in order to get the full control of water supply.¹⁸ The city's Ottoman governor, Ali Pasha, ordered the system be repaired and water start running again to the city, but it did not function for long. Based on the account of a German explorer who participated in a Danish expedition to Jeddah in 1762 CE, people in Jeddah were still bringing water from outside the city using camels as water carrier.¹⁹ This suggests that the canal system was not working or was not sufficient at that time period. Despite all the attempts to bring more water, the demand kept growing.

During the 18th century CE, people in Jeddah—especially merchants—began constructing cisterns under their houses to store the rainwater that was collected on the roof and then channeled downward in pipes. When the rain was insufficient to fill the cistern, they would bring water from natural catchment areas outside the city to fill it.²⁰ This type of rainwater harvesting system became well-known in many cities in the Arabian Peninsula, including Makkah, Yanbu, and Madinah (see Figure 3).

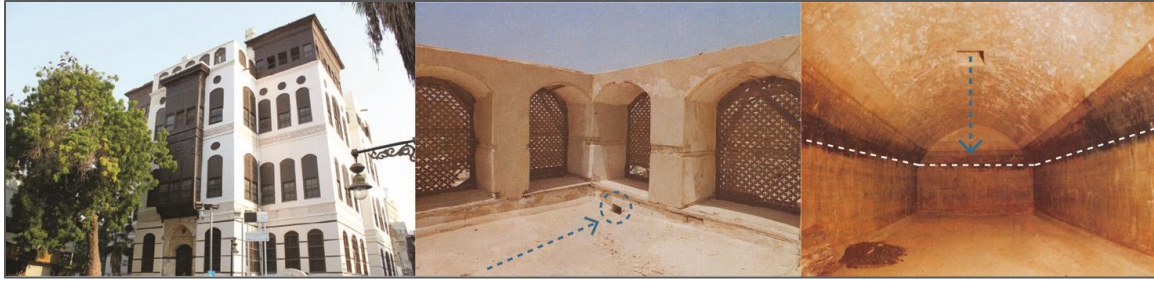


Figure 3 Traditional rooftop rainwater harvesting with underground cistern (Image of Nasif House, Source: The National Center for Research and Documentation at Jeddah City)

In 1853 CE a Jeddah merchant named Farj Yuser decided to take the lead in repairing the canal system to reconnect water to the city. He successfully raised funds from other merchants in Jeddah and was able to fix the system. However, the flow of the water was weak and, after a couple of years, the system again failed.²¹ After that, many rulers—such as Safwat Pasha and Nori Afandi—were able to fix the system temporarily, but the system was in bad condition and did not survive long after.²² Instead of relying on water to be supplied by the municipality, people continued to use the local runoff rainwater harvesting techniques and ground water for water supply.

Major advancements to modernize the Jeddah water supply would not take place until the 20th century CE. Beginning in the 19th century CE, the steam engine was successfully modified to maritime use. This led to the development of desalination techniques—the removing of salt from seawater to produce fresh drinkable water—being used on many seagoing ships and submarines in order to serve sailors on long trips.²³ This led to a fortunate accident. The Ottoman Empire possessed many steam ships and around 1907 CE, one of the Ottoman steam ships crashed near the coral reefs off of Jeddah’s coast. The authorities came up with the idea to solve the water scarcity problem in Jeddah City by relocating the desalination machine from the ship to the coast to be

used as an additional water supply system. Jeddah's citizens named this machine "Kandasa," based on its Western name "Condenser." This inventive solution created a new culture for water use and water supply in the city. The Kandasa water was used only for drinking and cooking, while the rainwater harvested in the cisterns was used for any other purpose like washing and irrigation (people named this latter type of water *Alrdykh*, which meant "not clean"). The person who carried the Kandasa's water to the houses was called the *Saqa*. These men also had a job rank based on the time they served as Saqa and received promotions that would allow them to carry more water. The Saqas also had a formal leader called the "Shekh Al Saqa" because it was his job to organize the Saqas and resolve issues regarding water use (see Figure 4).²⁴

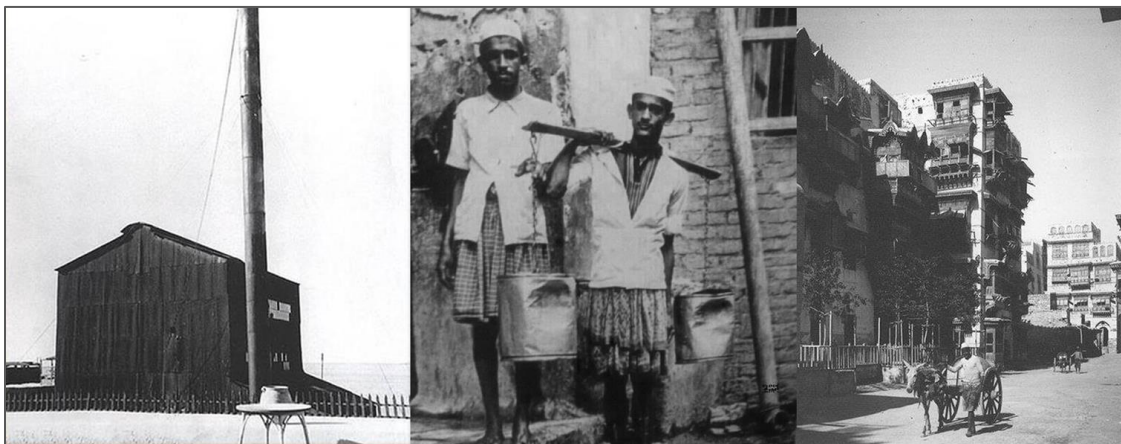


Figure 4 Images of local desalination facility (Kandasa) and alsaka, a person who carries the water
(Source: The National Center for Research and Documentation database at Jeddah City)

Each Saqa took care of the water needs for a number of houses in Jeddah City. The daily maximum production of the Kandasa was 300 cubic meters, equal to 79,260 US gallons of water.²⁵ Based on the World Water Assessment Program (WWAP), the United Nation today recommends that "each person needs 20-50 liters (equal to 5-13 US gallons) of water a day to ensure their basic needs for drinking, cooking and cleaning."²⁶

This clearly shows that the Kandasa system was not enough to satisfy the overall demand of the people and, eventually, water became accessible only for people who could afford its high price. In 1925, due to a limited coal supply in the area, people began using firewood instead of coal to operate the Kandasa system, which damaged the system beyond repair. After that, rainwater harvesting again became the main supply for water in Jeddah City.²⁷ In 1928, King Abdulaziz Al-Saud—the founder of the Kingdom of Saudi Arabia—recognized the water scarcity problem in Jeddah. He gave orders to provide two additional new systems for water desalination to meet the needs of Jeddah’s population and the pilgrims. Unfortunately, their efficiency began to decrease gradually as the population of Jeddah and the number of pilgrims also steadily increased.²⁸ Interestingly, the resources for solving Jeddah’s water needs would come hand-in-hand with Saudi Arabia’s nascent oil industry.

In 1933, King Abdulaziz allowed the Standard Oil of California Company (SOCAL) to search for oil in the Kingdom of Saudi Arabia, and they found large quantities near the Arabian Gulf in 1938.²⁹ This marked the beginning of the oil boom era in Saudi Arabia. During this time period, Jeddah merchants were studying the feasibility of bringing water from the nearby district of Wadi Fatma. Hearing of this plan, King Abdul Aziz ordered that a project for supplying water to Jeddah from Wadi Fatma should be executed and fully funded by him. In 1945, the Mohammed Bin Lادن Establishment was assigned to do this project, which was called “Al-Azizya Spring Project.”³⁰ This company signed a contract with a British company called Henki to supply and install the pipe system from Wadi Fatma to Jeddah City at a distance of 65 km, which was completed and began to flow in 1947.³¹ Water coming from Wadi Fatma was collected in

a cistern located outside the city and then distributed through a pipe system (called a *bazan*) in several locations inside the city. After that, the Saqa carried the water from the *bazan* to the houses either via donkey or on his shoulders using a sturdy yoke with two metal buckets, called an *alzfa* (see Figure 5).³²



Figure 5 Images of AlBazan and Alsaqa (Source: The National Center for Research and Documentation database at Jeddah City)

The huge amount of the water running into the city was more than needed and the oil boom and new water supply together supported the city's subsequent rapid development. The old city wall was demolished in 1947 and the city grew in all directions.³³ New small districts formed around the old city and they needed to be served by a modern water supply system as well. As a result, the Al-Azizya Spring Station began a project to construct a pipe network for the direct distribution of water to all the houses in Jeddah City, which ultimately made the role of the Saqa unnecessary.³⁴ However, just as increased availability of water allowed the population to expand, the continued growth of Jeddah City and the onset of its industrial revival meant that the consumption of water dramatically increased. The water supply from Wadi Fatma soon was not enough to meet the growing demand, and so, in 1958, an additional water supply from the district of Wadi Khaliss (at a distance of 150 km) was connected to Jeddah City.³⁵

In this short time period, Jeddah City witnessed massive urban growth. There was

a growing demand and pressure for new development, with people's needs and lifestyle becoming more modern and westernized. Although they enhanced their quality of life, these developments affected many aspects of the city's cultural heritage.³⁶ The government of Saudi Arabia was concerned about the growing demand of water in the country and thus, in 1965, launched a project for seawater desalination plants along the Kingdom's coastline at locations that included the Jeddah coast.

Today, Saudi Arabia is one of the leading countries that use water desalination techniques for water supply and Jeddah uses seawater desalination as the main water supply (supplemented by groundwater from Wadi Fatma and Wadi Khaliss). The traditional rainwater harvesting techniques, such as collecting rainwater from roofs, are no longer used.

2.2 Urbanization, Population, and Tourism Growth

Following the oil boom in 1938 and the connecting of the city to a new water supply system (along with demolishing the city wall) in 1947, the city experienced a massive unprecedented stage of development and rapid population growth. Local people abandoned their historic houses in the old city and moved out to resettle in modern Jeddah. The population has increased from about 40,000 inhabitants in 1947 to 1,250,000 in 1980. Today, Jeddah's total population is estimated at around 3,400,000 and, by 2029, it is expected reach over 5,000,000 (see Figure 6).³⁷ The city's strategic location as a gateway to the Two Holy Cities along with modern urbanization, changes in lifestyle, and new development (such as indoor shopping malls, amusement parks, international restaurants and hotels) make Jeddah City a highly attractive tourist destination. In 2003,

Jeddah City hosted over 12.5 million tourists, including both domestic and international tourists.³⁸ In 2010, the Saudi Commission for Tourism and Antiquities along with Jeddah Municipality and other private sectors prepared the nomination document for the Historical City of Jeddah inscription on the UNESCO world heritage list.³⁹ If and when UNESCO recognizes the historical city of Jeddah as World Heritage site, it will further encourage the growth of economy and tourism in Jeddah. Although tourism growth will boost the economy, it will also increase the pressure on natural resources, leading to environmental degradation.

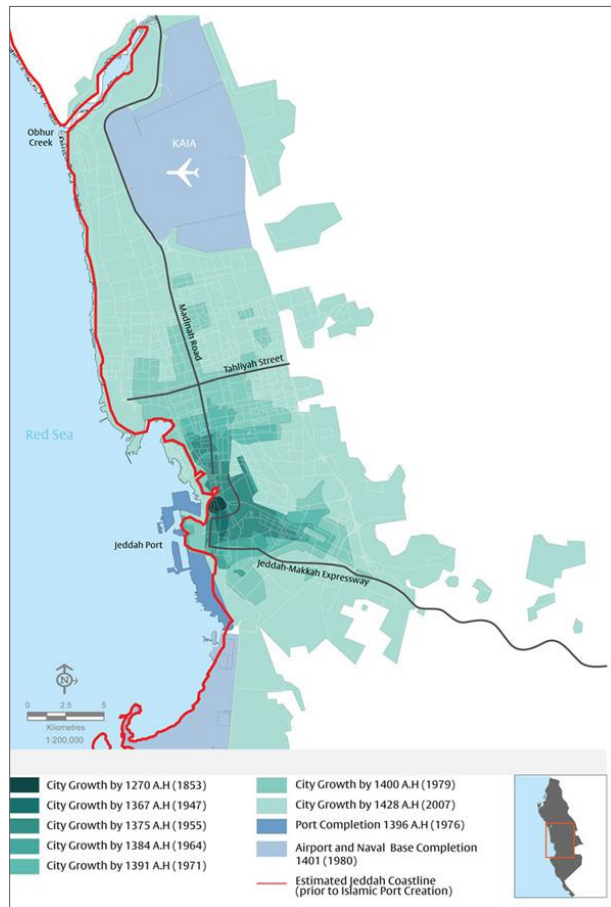


Figure 6 Jeddah City growth map (Source: Jeddah Municipality.2013.Jeddah Strategic Plan-Introduction, p.16)

Historically, the city of Jeddah had no gardens due to water scarcity. There were only a few date trees located next to one of the mosques, a few low acacia trees, and some shrubs located along the seashore. The rest of the landscape was mostly a natural barren desert.⁴⁰ However, in less than four decades, Jeddah City has experienced a radical transformation of urban development, including an increase in gardens. In 1987, the total landscape and green area reached 7 million square meters, and by 1994, the green area had increased to around 9.2 million square meters. This figure includes public gardens, plazas, squares, street trees, and most importantly the development of the Jeddah waterfront (known as the Corniche) as the main public open space for Jeddah City.⁴¹ The Jeddah Corniche is situated on the western part of the city and expands for almost 100 kilometers along the Red Sea coastline. It includes the magnificent King Fahd Fountain, an open art gallery with a wide collection of sculptures and modern artworks, private beaches, restaurants, walkways, playgrounds, and amusement parks (see Figure 7).

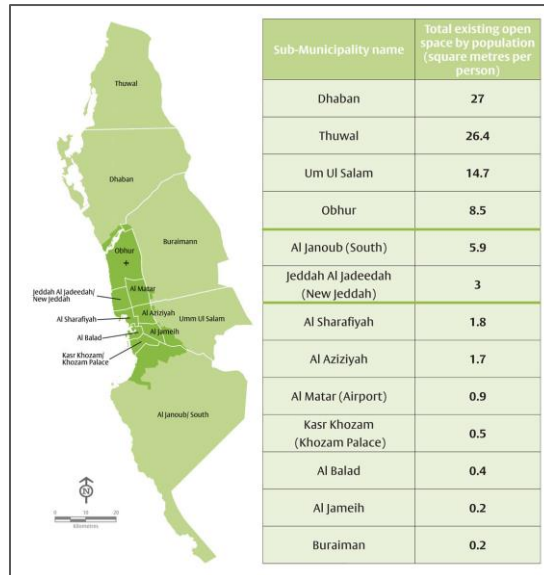


Figure 7 Existing open space in Jeddah (Source: Jeddah Municipality.2013.Jeddah strategic plan- open spaces and Leisure, p.310)

The new parks and landscape projects have increased the pressure on the water supply, as they require regular irrigation. To overcome this problem, Jeddah municipality has built small wastewater treatment facilities and used the recycled treated water as the main source for landscape irrigation.⁴² In comparison to other methods like rainwater harvesting, wastewater treatment is considerably more expensive. This method consumes natural energy (namely, fossil fuels) and requires continuous maintenance. In addition, the treatment process includes various chemicals that can poison the environment.

With the rapid urban development and population growth, the area reserved for gardens and landscape has decreased over time. Today, the open spaces in Jeddah are insufficient to meet the demands of residents. According to the Jeddah Strategic Plan for the city, “The World Health Organization (WHO) recommends eight square meters of open space per person as a minimum provision. With an average provision of only two square meters of open space per person in most districts, Jeddah currently falls significantly short of this target.”⁴³ Jeddah’s lack of adequate green spaces impacts more than just the economic potential of the city. Green spaces have a wide range of benefits that significantly contribute to human health and enhance overall environmental quality including the maintenance of natural landscape processes, providing cleaner air and water, enriching habitats and biodiversity, increasing recreational opportunities, improving health, and encouraging a better connection to nature and sense of place.⁴⁴ Therefore, the absence of sufficient green open spaces and irrigation system in urban areas may affect the natural ecosystem leading to environment issues, and it may in turn have a detrimental effect on human communities.

However, the city's water supply issues are even more precarious than other issues affecting health and human welfare. There are no permanent rivers or lakes and very little rainfall in Jeddah City. Water production and transport costs are quite high; yet the Saudi government provides it at a price below the actual cost. As a result, people have no intention to save water or use it economically. The municipality of Jeddah City stated, "The current water supply capacity cannot meet the current demand from the city."⁴⁵ As Jeddah's population continues to grow, demand will increase for water and green open spaces in both existing and new areas. Jeddah municipality needs to address the water issues by making a plan to reduce water consumption and maximize the efficiency of the existing supply (see Figure 8).

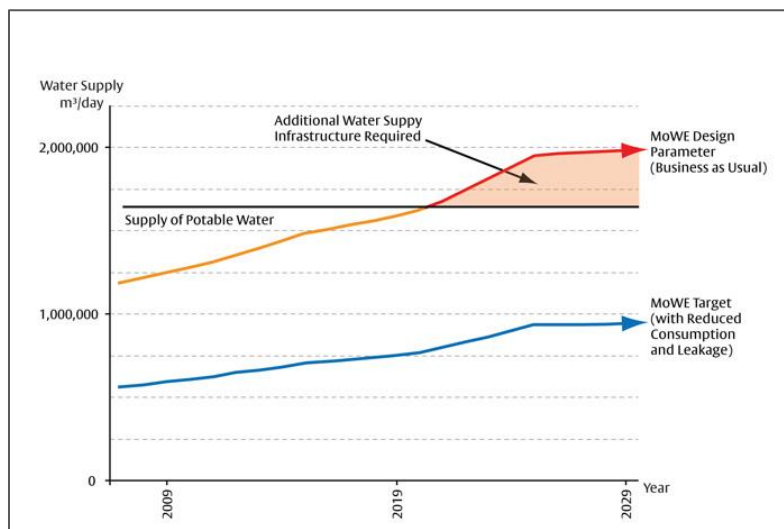


Figure 8 Water consumption and supply capacity (Source: Jeddah Municipality.2013.Jeddah strategic plan-Infrastructure, p.260)

2.3 Climate Change

According to the United States Environmental Protection Agency, climate change refers to “any significant change in the measures of climate lasting for an extended period of time.”⁴⁶ Climate change is one of the most significant environmental concerns and the ultimate global challenges in society today.

A recent study done by Muhammad Amin⁴⁷ found an increased trend of annual total rainfall in six cities in Saudi Arabia, including Jeddah City. This climate change causes extreme weather events around the country. Coupled with the rapid urbanization, this increased volume of storm water runoff leads to soil erosion, flooding, and the degradation of in-stream ecosystem health. Today, urban floods have become the most frequently encountered natural disaster in Jeddah City, causing severe damage to human lives, property, and livestock. Flooding can also cause epidemics due to improper sewer disposal and contaminated water supplies.

In 2009, heavy rains that lasted for only a few hours, but caused massive flooding, afflicted Jeddah City. More than 120 people died, while 22,000 people were displaced and 8,000 homes and 10,000 vehicles were destroyed.⁴⁸ In 2011, Jeddah City again suffered from flash floods that caused severe damage (see Figure 9).



Figure 9 Jeddah Floods (Source: Alsharif, Mo. (photographer) (2009) Jeddah floods. Retrieved May 05, 2013, from: <https://www.flickr.com/photos/7336409@N07/4159870202/>)

In response, Jeddah Municipality launched billion-dollar contracts to implement permanent flood and rainwater drainage projects in Jeddah in 2012.⁴⁹ The project included five new dams, drainage channels in the north, south, and east, and a new floodwater drainage system at the airport.⁵⁰ While these massive conventional storm water management projects might solve the problem of natural flooding, these are not sustainable solutions. Jeddah City needs more than one solution for managing storm water in a more ecologically sustainable fashion. What is needed instead is a sustainable approach such as applying rainwater harvesting and green infrastructure to provide an additional water supply and improve the overall environment.

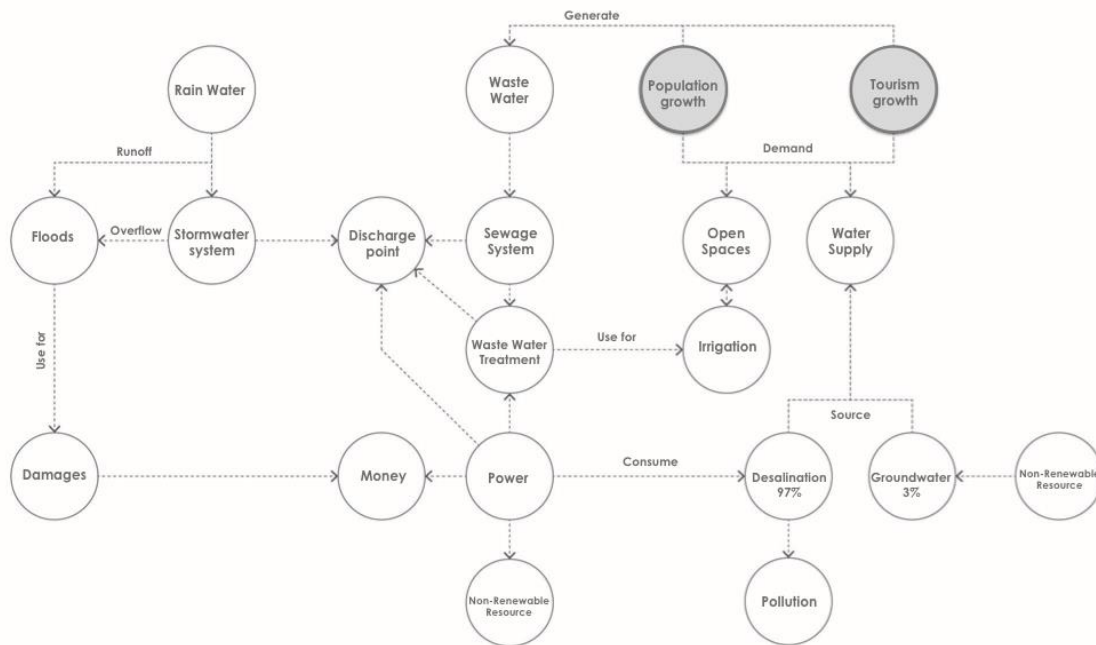


Figure 10 Diagram demonstrating and analyzing the current water management system in Jeddah City
(Source: Author)

CHAPTER 3

LITERATURE REVIEW

There is considerable literature on the techniques and relative efficiencies of rainwater harvesting (RWH), green infrastructure, and the general barriers impeding the implementation of these techniques. The purpose of this review is to explore and evaluate the potential transferability of the modern practices and methods of rainwater harvesting and storm water management to the historic environment of Jeddah City.

3.1 Rainwater Harvesting

According to *Design for Water* by Heather Kinkade Levario,⁵¹ rainwater harvesting (RWH) can refer to any type of methods that captures, moves, and stores the runoff from various sources and for unlimited purposes. Generally, the RWH system has four main components: a catchment area, conveyance, storage, and distribution system. Rainwater harvesting has been practiced by many cultures around the world to meet plant-cultivation, human, and animal needs, and some of the earliest RWH systems are found in the Middle East, Asia, and Europe. Archeological surveys in the Middle East discovered the remains of an RWH system in the form of reservoir and underground cisterns dating from 9,000 years ago in Edom Mountain in southern Jordan.⁵² In India, a basic stone structure for the purpose of RWH was found that dates back to 3000 BCE. There is also evidence of a civilization dating back to 3000 BCE in the Negev Desert of Israel that was used to capture storm water and store it in cisterns. In Ancient Rome, rainwater was collected from building rooftops and use for both domestic and landscape

purposes.⁵³ Today, in addition to addressing the stresses caused by population growth, climate change and water scarcity in MENA regions, and particularly in Jeddah City, RWH has the potential to provide additional water supply for drinking and irrigation.

Rain is the primary source of fresh water for most people on earth and it is a high-quality, sustainable water source. In the *Municipal Handbook for Rainwater Harvesting*, Christopher Kloss explains that the practice of RWH provides many economic, environmental, and ecological benefits.⁵⁴ Harvesting rainwater can significantly reduce the pressure on existing municipal water supplies, resulting in a substantial reduction of energy and economic expenses related to the production and delivery of water to consumers. In addition, RWH can reduce surface runoff, thus preventing soil erosion and storm water flows or flooding that individually and together can cause surface water pollution and structural damage. Rainwater is ideal for landscape use because it can reduce the salt accumulation in the soil (a common problem in irrigation systems) and flush it away from the root zone area, allowing for a healthy root growth.⁵⁵ As previously mentioned, Jeddah receives an average of 53.5mm amount of rainwater annually and this is enough for rainwater harvesting to potentially bring similar benefits to Jeddah City.

According to *Design for Water*, the RWH system can be categorized into two types – passive and active (see Figure 11). Passive RWH systems collect the rainwater from any low infiltration surface area and move it to a landscape area for direct, immediate use on site. Examples of a passive system include rain gardens, bioswales, constructed wetlands, tree boxes, and green streets. Active RWH systems collect the runoff from the catchment area and store it in cisterns for future use.⁵⁶

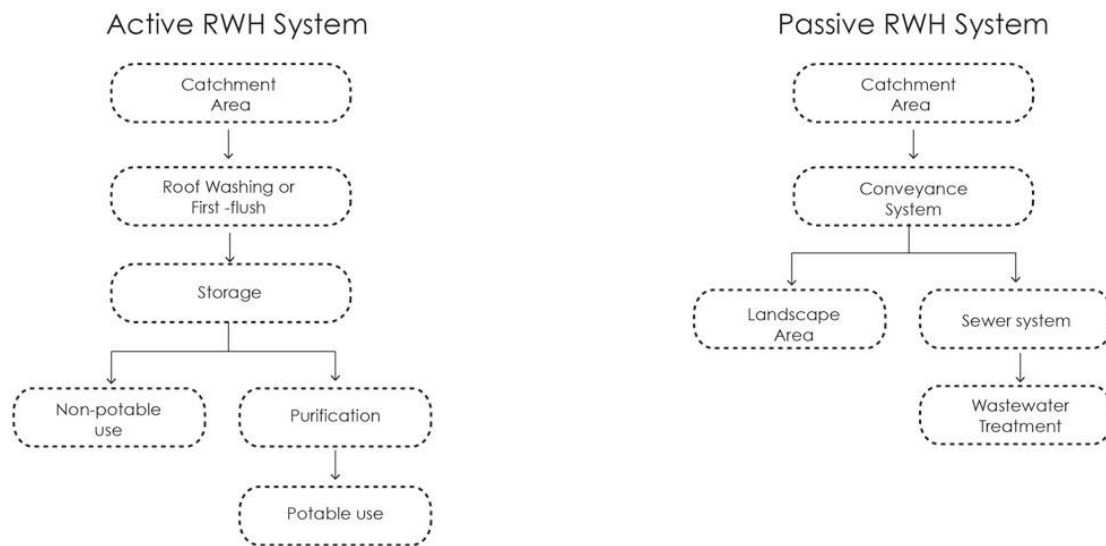


Figure 11 Diagram of active and passive RWH system (Source: Adapted from, Kinkade-Levario, Heather. 2007. *Design for Water-Rainwater Harvesting*. 15)

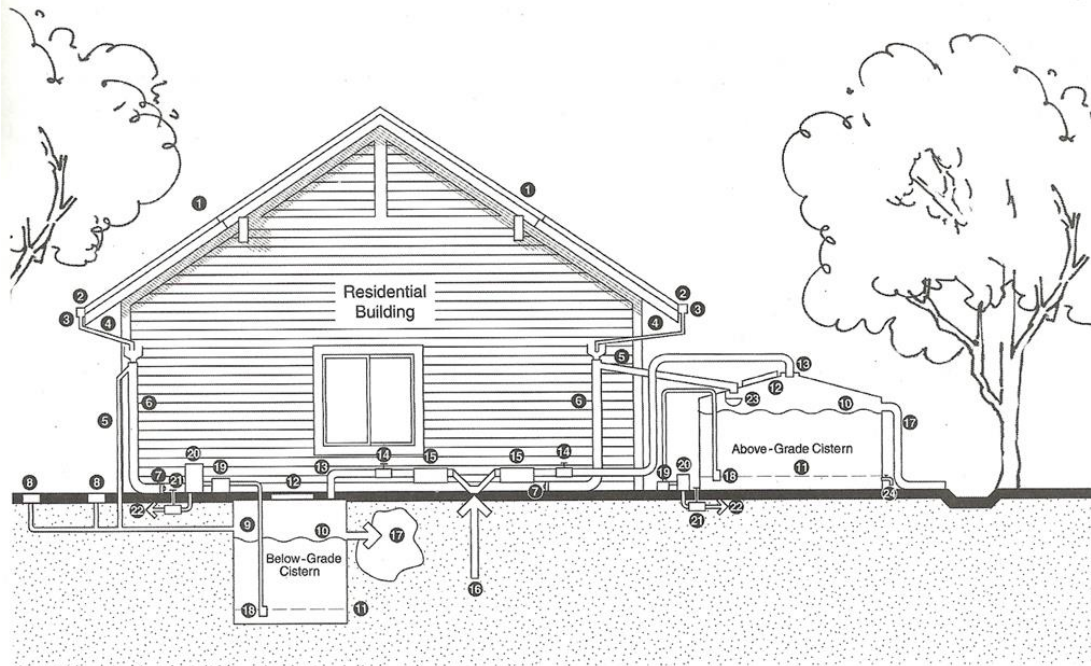
These two rainwater harvesting systems are the basis of the modern green practices that manage storm water by using ecological and natural process to create healthier urban environments. Rainwater can be captured from any impervious surface. Typically, a rooftop catchment surface is the most common, simple, clean, and cost-effective method for potable and non-potable use. In contrast, ground-level catchment areas—such as parking lots, streets and channeled gullies—are mostly used for non-potable use because of the higher risk of pollution. However, if the distribution system for the ground-level catchment contains a sufficient purification system, then it can also be used for drinking.⁵⁷ The conveyance system mostly consists of gutter and downspouts that move the rainwater from the rooftop to cisterns or a landscape area. The roof washing includes a “first flush” system that filters and screens the unwanted deposits of debris, leaves, and pollutants before they enter the storage container, thus guaranteeing a certain degree of water quality in harvested rainwater.⁵⁸

For centuries, people in Jeddah City have practiced this kind of a system, using their rooftops to capture rainwater and storing it in underground cisterns. However, based on the historical investigation presented in Chapter 2, we know that water quality was a continuous concern in Jeddah City. Therefore, modern purification solutions for rainwater harvesting are needed in Jeddah City to ensure good water quality. The solutions can easily be retrofitted to current RWH systems in Jeddah and also should be included in new ones.

The storage system is typically the most expensive component of a rainwater harvesting system. It is available in three types: surface storage, underground storage, and integral storage built into a property.⁵⁹ The storage selection depends on several technical and economic considerations, such as the space availability, storage capacity, and cost. However, whether or not rainwater can be conveyed by natural gravity or by pumping depends on its location; rooftop cisterns can use gravity, but basement cisterns require pumps to raise the water to where it will be used. If the rainwater is to be used for drinking, then the rainwater must first be transferred to a purification system and then distributed from there to the points of use. In the case of Jeddah's historical old city, rainwater was mostly stored in underground cisterns.

In some areas, dry ponds were also used to capture and temporarily store storm water runoff. Currently, the majority, if not all, of the buildings in modern Jeddah have underground storage tanks built into the property that are used only to store water obtained from the municipality. To retrofit the RWH system for these properties, the most applicable storage type is surface storage. However, as I discussed earlier, there are many important considerations that require a detailed assessment for each individual

property before retrofitting any storage for rainwater harvesting (see Figure 12).



Detail 2.2

Typical components of a residential building rainwater harvesting system for landscape irrigation

NOTE: Both above-grade and below-grade cisterns are shown. For residential systems, either may be appropriate. It is not necessary to have both types of systems. Cistern size and catchment area should be balanced for maximum accumulated storage. Not all site rainfall runoff needs to be directed to cistern, only the quantity required to maintain the proposed landscape irrigation budget.

1. Rooftop collection.
2. Gutter with leaf screen if building is adjacent to trees.
3. Five- to six-inch gutters, sized per local plumbing code.
4. Downspout sized per local plumbing code, sediment trap for ground-level catchment or direct to cistern.
5. Pipe to cistern, typically 4-inch diameter schedule 40 PVC pipe.
6. Debris and sediment interceptor, first-flush device.
7. Screw-off end cap for cleaning.
8. Catchbasin for paved/hard surface ground-level runoff collection, with sediment trap.
9. Rainwater inlet, inlet to cistern must be a minimum of 10 inches below top of cistern. An inflow smoothing filter may be appropriate at this location depending on proximity of rainwater inlet to irrigation supply filter. The smoothing filter will slow rainwater inlet turbulence that may disturb the fine sediment settled on the bottom of the cistern.
10. Maximum water level to be 12 inches below top of cistern.
11. Minimal level of water to maintain priming in landscape irrigation pump (approximately 12 inches), level of water to be determined by engineer or irrigation specialist.
12. Twenty-four inch access for cleaning.
13. Alternate water supply, must not obstruct the 24-inch access. Alternate water supply may be proposed for a cistern manual-fill option for droughts and plant establishment periods when additional water is required. Alternate water supply may also be automatic for fill option when rainwater supplies are inefficient.
14. Typical valve.
15. Atmospheric vacuum breaker.
16. Alternate water source, possibly domestic or municipal supply.
17. Cistern overflow (same size as inlet) to a dry well or gravity outlet to landscape basin if site conditions allow. An additional option would be to outlet to an adjacent flood retention underground storage pipe that is tied to a dry well. Cistern overflow must be a minimum of 12 inches below top of cistern to avoid contamination of alternate water supply, or be 6 inches below any debris strainers in an above-grade cistern.
18. Landscape irrigation supply filter with automatic shutoff to maintain priming in pump if water falls below minimum level in cistern. Locate filter a minimum of 6 inches from cistern bottom to avoid settled fine sediment.
19. Optional sand filter.
20. Landscape irrigation pump and pressure tank.
21. Typical valve.
22. Water supply line for irrigation system.
23. Removable leaf and debris strainer basket.
24. Hose bib for draining cistern.

Figure 12 Rainwater harvesting for residential buildings (Source Kinkade-Levario, *Design for Water-Rainwater Harvesting*, 17)

In order to promote rainwater harvesting in Jeddah City, the Saudi government should provide regulation that requires implementation of RWH into new development

or/and offers incentives that will motivate building owners to comply with current best RWH practice. These regulations and incentives should be supported with easily available design manuals developed by municipalities for different rainwater harvesting techniques suitable to the local condition of cities in Saudi Arabia.

3.2 Green Infrastructure and its Benefits

More than ten years ago, Benedict and MacMahon wrote: “Green infrastructure is a new term, but it’s not a new idea.”⁶⁰ The concept is based on the ancient practice of rainwater harvesting within a wider ecological framework that contributes significantly to human health and well-being. Green Infrastructure (GI) has various definitions, depending on the framework in which it is used. One of the most frequently used definitions in literature is: “An interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife. Used in this context, green infrastructure is the ecological framework for environmental, social, and economic health – in short, our natural life-support system.”⁶¹ The U.S. Environmental Protection Agency defines GI as an “adaptable term used to describe an array of products, technologies, and practices that use natural systems—or engineered systems that mimic natural processes—to enhance overall environmental quality and provide utility services.”⁶² Green Infrastructure practices are flexible and can be incorporated into various built environments at many different spatial scales as well as many development settings that include new development, revitalization, and retrofit projects.⁶³

Research on GI performance indicates that GI systems are capable of achieving several functions and providing a wide range of benefits.⁶⁴ Because they have the ability to protect and restore a wide range of natural ecosystems, GI systems can be used to establish a framework for future sustainable development. They provide diverse ecological, social, and economic benefits including: the maintenance of natural landscape processes, cleaner air and water, a habitat characterized by biodiversity, increased opportunities for the enjoyment of nature, better human health, and a better sense of being connected to a place.⁶⁵ In addition, GI helps the preservation and development of green landscape, which also has many benefits. Property values usually increase and the costs of public infrastructure and public services usually decrease, including the costs of handling storm water and maintaining water treatment systems.⁶⁶

In addition, there is also a growing body of evidence that indicates that GI solutions can contribute significantly to human health and well-being. Many studies confirm that a healthy natural ecosystem has a beneficial outcome to human physical health, through improved air and water quality.⁶⁷ Several other studies suggest that GI features that encourage contact with nature have the potential to improve other forms of health, especially psychological and emotional health of individuals and larger communities. This is because direct and indirect access to natural places allows people to relax and clear their minds, which results in better cognitive and emotional functioning.⁶⁸ Green Infrastructure also plays an important role at the community level. Parks and green spaces encourage social interactions and promote a sense of community spirit by encouraging people to walk (so that they are more likely to interact with each other) and giving them easy access to green open spaces (see Figure 13).⁶⁹

Green Infrastructure Benefits		Value				Reference			
		Environmental	Economical	Social	Cultural	Benedict & McMahon	Kambites & Owen 2006	Schilling & Logan 2008	Banking on green report 2012
1	Habitats for species						x		x
2	Permeability for migrating species					x			
3	Connecting habitats					x	x		
4	Landscape restoration - regeneration of degraded sites					x	x		
5	Mitigating urban heat island effect							x	x
6	Strengthening ecosystem								x
7	Storing and reduce the risk of flooding ,storm water management					x	x	x	x
8	Sustainable waste management								x
9	Carbon sequestration								x
10	Encouraging sustainable travel						x		
11	Sustainable energy use- saving energy and cost							x	x
12	promote the renewable energy								x
13	Sustainable drainage system					x			x
14	Groundwater infiltration						x		
15	Clean water					x	x		x
16	Food security						x		
17	Soil development and nutrient cycle					x			
18	preventing soil erosion								x
19	Recreation , Exercies,sport					x	x	x	
20	Sence of space and nature					x			
21	Cleaner air					x	x		x
22	positive impact on land and property					x		x	x
23	Local distinctiveness						x		
24	Opportunities for education, and social interaction						x	x	
25	Tourism Opportunities						x		
26	Community developmet and cohesion						x		
27	Provision of space for public activites						x		
28	Walkable communitis							x	
29	Increase awareness of environmetnal issues					x			
30	Heritage preservation and cultural expression					x			
31	improve public health and mental well-being					x	x	x	x
32	Links between town and country						x		
33	Increased quality of life								x
34	Improve image of the town/city							x	
35	Reduce ADHD in Children							x	
36	Improve self discipline in inner city girls							x	
37	Reduce crime and domistic violence						x	x	
38	Increase physical activites opportunities							x	
39	Increase potienal consumer spending							x	
40	Increase access to healthy food						x		

Figure 13 Benefits supplied by green infrastructure (Sources: Benedict & McMahon 2006, Kambites & Owen 2006, Schilling & Logan 2008 and Banking on Green Report 2012)

Moreover, GI features enhance the beauty of neighborhoods, which in turn typically affects the market value of properties already there as well as and attracting new business investments to the area. The research clearly shows that improving the GI of a neighborhood positively affects many socio-economic aspects of its residents, such as by

increasing incomes, creating more employment opportunities, and improving working conditions.⁷⁰

Although the existing research has mostly been conducted in Western countries, particularly in U.S and U.K, cities in MENA regions could gain many similar benefits from GI systems. Especially in the case of Jeddah City, a carefully managed GI system will help to reduce urban flooding and water pollution issues. In addition, it will provide recreational opportunities for the city through green spaces, which in turn will improve community health. The challenge in those contexts lies in the policy-making arena, particularly in how to develop a comprehensive strategy to deliver such benefits.

3.3 Storm Water Management Design Strategies

There are many types of methods and strategies for storm water management. These include green infrastructure (GI) and best management practices (BMP), which is also known as integrated management practices (IMP) and low impact development (LID). With few variations, I found that all the terms mentioned above have many similar design strategies for storm water management that are based on natural processes. I used the database provided on the U.S. Environmental Protection Agency (EPA) website (www.epa.gov) to review the storm water management approaches mentioned above and I came up with a list of the most common practices for storm water management that can be applied at the site development level. I categorized them into three types based on their function.

3.3.1 Rooftop and Downspout Controls

Rainwater can be captured from rooftops and stored for later use. A downspout is a pipe that moves rainwater from the rooftop to the end point that could be a storage tank, landscape area, or paved surface. Below, I have identified several green storm water management practices associated with buildings that include: green roofs, green walls, blue roofs, and cistern and rain barrels.

First, a green roof (also known as living roof, eco roofs, vegetated roof, and rooftop garden) consists of soil and plants that are applied to a rooftop to provide a wide range of benefits. In some parts of the world, the green roof is a traditional practice. In the 16th century, the Mughal Emperor Jahangir was visiting Kashmir, India during the winter season and he noticed plants growing on the rooftops of the buildings.⁷¹ It is possible that people used green roofs to keep their home warmer during cold winters. In the 21st century, the green roof became a sustainable practice. According to the EPA, green roofs reduce energy use, reduce air pollution, improve human health, and enhance storm water management and water quality.⁷² There are two types of green roofs – extensive and intensive. An extensive green roof can be described as a vegetated roof with low maintenance and irrigation requirements. Typically, extensive roofs have 3-4 inches of growing medium. An intensive green roof, on the other hand, can include many plants types including grasses, shrubs, and trees. However, it also requires continuous maintenance and irrigation (see Figure 14).⁷³



Figure 14 Examples of green roof design (Source: Center for Neighborhood Technology.2010. The Value of Green Infrastructure, A Guide to Recognizing Its Economic, Environmental and Social Benefits, p.5)

Second, green walls (also known as vertical gardens, bio-walls, and living walls) are vertical or liner structures that are covered with vegetation. The idea of the green wall is not new; it has been used in many places for aesthetic purposes. However, the idea of green walls was only put forward as an important tool for sustainable architecture by Patrick Blanc in the mid-1990s, after he designed and built one of the most famous green walls at the Musée du Quai Branly in Paris. Modern green wall techniques have the ability to provide many benefits for humans, the environment, and buildings. These benefits include, but are not limited to, improving air quality, increasing biodiversity, reducing urban heat-island effect, building protection, reducing noise, and improving human health and well-being (see Figure 15).⁷⁴



Figure 15 Examples of green wall design (Source: GSky Plant Systems, Inc.2013.Project Gallery. Retrieved April 2 2014, from: <http://gsky.com/gallery/>)

Third, “blue roof” is a term that describes a non-vegetated roof design that is intended to manage storm water. Depending on their design, blue roofs have the ability to

temporally store rainwater that can be reused for irrigation, cooling the roof, and for non-potable domestic use (see Figure 16).⁷⁵



Figure 16 Examples of blue roofs design (Source: from left to right: Gowanus Canal Conservancy, “What is Green Infrastructure.” Retrieved April 10 2014, from: www.gowanuscanalconservancy.org. NYC Environmental Protection, “Blue Roof and Green Roof.” Retrieved April 9 2014, from: www.nyc.gov. Hazen and Sawyer, .2011, “Innovative Blue Roof/Green Roof Design Wins DEP Grant.” Retrieved April 14 2014, from: www.hazenandsawyer.com/news/innovative-blue-roof-green-roof-design-wins-dep-grant/)

Fourth, rain barrels and cisterns are two efficient types of storage tanks that are used to store the rainwater that flows down from the rooftop. Cisterns are considerably larger than rain barrels and thus can store significantly more water. In addition, cisterns can be placed both above ground and underground. Rain barrels, in contrast, are typically used for single-family houses and are placed outside the actual building and attached to the downspout. Using cisterns and rain barrels helps reduce storm water runoff while at the same time providing additional water supply that can use for irrigation or/and for non-potable use (see Figure 17).⁷⁶



Figure 17 Examples of rain barrels and cisterns (Sources from left to right: Wascana and Upper Qu’Appelle Watersheds Association Taking Responsibility.2013.Retrieved April 10 2014, from: wuqwatr.ca. Katrina Logan (designer),LUMI Rainwater Tank. Retrieved April 11 2014, from: <http://www.fulltank.com.au>. Houzz, Inc., 2014, Rain Barrel. Retrieved April 12 2014, from: <http://www.houzz.com/photos/outdoor-products/gallon-rain-barrel>. The Rain Catcher Inc., 2011, Cistern. Retrieved April 1 2014, from: <http://www.theraincatcherinc.com>)

3.3.2 Infiltration and Filtration

Infiltration and filtration are strategies for managing the impact and quality of storm water. Infiltration systems capture storm water runoff and hold it for slow infiltration into the ground, instead of allowing it to run off the surface (and possibly cause flooding elsewhere). Infiltration systems include, but are not limited to, the following strategies: rain gardens, bioswales, trenches, and permeable paving. Filtration systems (also known as bio-filtration) are used to remove sediment and other impurities from storm water using natural filtering media, such as sand and gravel.⁷⁷

Rain gardens and bioswales are infiltration storm water management strategies that reduce storm water runoff by encouraging it to be absorbed by a vegetated landscape. Both of these strategies are designed to capture, treat, and infiltrate storm water. The major difference between these two strategies is that while rain gardens are designed to hold the water on site, bioswales are designed as a channel that transfers storm water from the source to a green storm water management facility as slowly as possible. They are different with respect to scale: rain gardens can be built for small residential sites whereas bioswales are better suited to a larger area such as a neighborhood.⁷⁸

Infiltration trenches are linear ditches that collect storm water and release it into the ground by infiltration. The main purpose of infiltration trenches is to ensure water quality by removing pollutants from storm water runoff. In addition to water quality, infiltration trenches increase groundwater recharge. However, infiltration trenches also require proper maintenance to avoid groundwater contamination (see Figure 18).⁷⁹



Figure 18 Examples of infiltration systems (Source from left to right: spiire.2010. Street Rain garden project at Montmorency Australia. Retrieved March 15 2014, from: <http://www.spiire.com.au/case-studies/were-street-raingarden>. City of Victoria, 2012, Trent Street Rain Garden. Retrieved April 13 2014, from: www.victoria.ca. Lake County, Bioswale. Retrieved April 15, from: www.lakecountyl.gov. Landscape Architecture Foundation, Infiltration trenches .Retrieved April 15 2014, from: <http://lafoundation.org>)

Permeable pavement is designed to allow storm water to drain through the porous surface into either an underground storage tank or the subsoil in order to recharge the groundwater and replace materials like asphalt or concrete paving. As a result, it reduces storm water runoff, pollutants, and the urban heat-island effect. In addition, there are many types of permeable pavement; examples include pervious concrete and interlocking pavers. Permeable pavement can be used for many surface areas such as walkways, bike trails, and parking lots.⁸⁰

Tree box filters are containers situated beneath and around planted trees or shrubs to manage storm water runoff. The container includes a soil mixture, a mulch layer, and an under-drain system. The tree box improves water quality, urban aesthetics, and controls runoff by providing some detention capacity.⁸¹

A green gutter is a narrow strip that runs along the street's edge that captures and slows the storm water runoff. In addition to filtering storm water, green gutters also enhance the experience of pedestrians by providing green buffers between walkways and streets. Green gutters are ideal for different urban settings; however, a gutter requires a long, continuous run to slow and filter the storm water that flows into it.⁸²

A storm water planter (also known as infiltration planter, flow-through planter,

and contained planter) is a smaller version of a rain garden that can decrease storm water quantity and improve water quality. It captures, treats, and then infiltrates storm water into the ground. Because storm water planters are flexible in their size and shape, they can be placed in many different kinds of urban settings including streets, parking lots, and commercial properties (see Figure 19).⁸³



Figure 19 Examples of infiltration and filtration systems (Source: Nevue Ngan Associates. 2009. San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook. Filtterra Bioretention Systems. Tree Box Photo Gallery. Retrieve April 1 2014, from: www.filtterra.com)

Conventional curb extensions are additional areas that are generated by extending the sidewalk into the parking lane in order to increase pedestrian safety. A storm water curb extension (also known as vegetated curb extensions) works similarly but uses the extension to capture filtrated and infiltrated storm water runoff. Storm water curb extensions have flexible shape and size requirements and can easily be retrofitted to existing streets.⁸⁴

Detention is a strategy that manages storm water runoff by temporarily storing it and then releasing it at a controlled rate. Examples of this system include dry detention ponds and detention vaults. Retention, in contrast, is a management strategy that requires a permanent structure to store the runoff. Examples of this system include retention basins and storm water wetlands.⁸⁵

Further recommendations for technical specifications and design guidelines for many of these and other green storm water infrastructure practices include: (1) the *San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook* (http://www.flowstobay.org/files/greenstreets/GreenStreets_booklayout_Guidebook.pdf), (2) the *New York State Storm Water Management Design Manual* (<http://www.dec.ny.gov/chemical/29072.html>), (3) the *San Francisco Storm Water Design Guidelines* (<http://www.sfwater.org/Modules/ShowDocument.aspx?documentID=2779>), (4) the *Missouri Guide to Green Infrastructure* ([http://www.dnr.mo.gov/env/wpp/storm water/mo-gi-guide.htm](http://www.dnr.mo.gov/env/wpp/storm%20water/mo-gi-guide.htm)), and (5) the EPA “Storm Water Management Database” ([http://www.epa.gov/greeningepa/storm water/more_information.htm](http://www.epa.gov/greeningepa/storm%20water/more_information.htm)).

3.4 Barriers and Gateways to Sustainable Storm Water Management

There are numerous studies that describe the multiple benefits of green storm water management practices that include GI. Despite the evidence, practitioners, landowners, and city managers sometimes resist the adoption of these green practices. Many successful case studies demonstrate that such barriers to green storm water management practices could be overcome in many ways, including through research and by establishing the necessary technical support that would help cities, communities, and individuals design and apply green storm water management systems. Moreover, acknowledging that these green practices can add value to properties may also help overcome some of the barriers that are being faced. In Jeddah City, we have the opportunity to promote the idea of GI as a traditional practice of water harvesting that people of Jeddah were already practicing long before modern GI was established.

In this section, I identify a broad array of the most common barriers that confront municipalities, developers, and engineers in adopting green storm water management strategies, specifically GI approaches, and suggest some strategies to overcome them. I used a number of sources, including reports from The Clean Water America Alliance,⁸⁶ Environmental Protection Agency⁸⁷ and Regional Plan Association.⁸⁸ These sources show that there are four types of barriers to implementing GI: technical and physical barriers, legal and regulatory barriers, financial barriers, and community and institutional barriers.

3.4.1 Barriers Confronting Municipalities

Studies show that local governments are the main supporter of larger-scale, storm water management projects that use GI strategies. However, these local bodies also face many difficult challenges, in the form of limited resources, fragmented responsibilities, and a low tolerance for risk.⁸⁹ Based on an electronic survey done in 2012 to identify the largest barriers to GI in the Hudson Valley (New York State), cost was listed as the number one barrier to GI implementation in almost a third of the total responses; 25% of the respondents confessed to ignorance; and 22% mentioned unfamiliarity and resistance from their own local governments.⁹⁰

In the case of Jeddah City, the municipality has both legal and financial resources to apply and enforce decisions and regulations. As I mentioned earlier in Chapter 2, in 2012, Jeddah municipality launched a billion-dollar project to build storm water drainage network using conventional gray infrastructure techniques. The aforementioned project implies that the municipality is fully aware of the storm water related problems and is

trying to solve the issue at any cost. As a result, the cost of implementing GI in Jeddah is not the main barrier that is confronting the municipality. Instead, the municipality is more likely to face technical and physical barriers due to unfamiliarity with GI design, construction, and maintenance requirements. To overcome these issues, Jeddah's municipality can learn from international experiences in GI and, moreover, they also need to develop pilot programs to evaluate storm water management performance in their local environmental setting. This will help the city to establish a comprehensive design strategies and guidelines for storm water management using GI.

3.4.2 Barriers Confronting Developers

Even in the parts of the world where the research is being done to show that GI can produce significant benefits, many developers and practitioners are skeptical about GI's long-term performance. They look at GI as a new technology with limited resources. In Jeddah City, the current municipality's regulations and building codes often discourage private developers and public agencies from incorporating GI into their sites and buildings.⁹¹ In addition, many developers are reluctant to make the initial investment, because they are uncertain of the potential for cost savings with GI. Even if developers are able to calculate the potential cost savings, they may face building codes that do not conform to GI approaches.⁹² As I mentioned earlier, many of the strategies for overcoming these barriers require action by Jeddah municipalities in the form of new policies and incentives.⁹³

3.4.3 Barriers Confronting Designers

Green infrastructure approaches are extremely flexible and may be adapted to many places. Design barriers will be different, depending on the specific context; however many researchers and designers have been able to overcome most design challenges facing Green Infrastructure.⁹⁴ A full set of solutions can be found in these reports: The Clean Water America Alliance, Environmental Protection Agency, and Regional Plan Association.⁹⁵ Although all these reports are based on case studies in a Western context, we can assume that Jeddah City will have similar concerns and can benefit from it.

CHAPTER 4

RAINWATER FEASIBILITY STUDY

Knowing how much water is available is critical for the future of sustainable water management and landscape design. In Chapter 3, I demonstrated that rooftop rainwater capture provides a safe and efficient solution for water supply problems and offers numerous benefits to health of wellbeing. In the present chapter, I provide a general assessment for the feasibility of Rainwater Harvesting in residential urban settings in Jeddah City, Saudi Arabia. My principal focus is on the potential for capturing precipitation from existing rooftops.

4.1 Methodology

I developed three models to study the feasibility of urban rainwater harvesting in Jeddah City. The first model (Model 1) is intended to measure the potential rainwater harvesting volume in 1,000 square feet of surface area. The second model (Model 2) is intended to measure the water requirement for 1,000 square feet of landscape area. The third model (Model 3) measures the volume of rooftop rainwater available for capture in the historical city of Jeddah. In addition, Model 3 is based on a scenario that assumes that rooftop rainfall at the study area will use only captured-water for landscape irrigation.

To perform the technical analysis for Models 1 and 2, I used multiple government agencies databases as well as existing published research. These sources are provided in the bibliography at the end of the thesis.

The average annual rainfall for Jeddah City was calculated based on the monthly rainfall data included in the surface annual climatological report for Jeddah that cover the period between 1981 to 2011 (see Table 1). The annual climatological reports are obtained from the Ministry of Defense and Aviation-National Meteorology and Environment Center of Saudi Arabia. The plant water use factor was categorized based on water tolerance that ranges from Low, to Medium, and to High. This data was obtained from “Harvesting Rainwater for Landscape Use” (see Table 2).⁹⁶ The evapotranspiration ET_o data is obtained from the “Landscape Plant Manual for Saudi Arabia” by Geoff Ricks that is based on Jeddah climatological reports from 1966 to 1982 (see Table 3).⁹⁷ The area for both rain catchment surface and landscape surface are measured based on an assumption of 1,000 square feet of surface area. To perform the technical analysis for the study area (Model 3), I used the findings from Model 1 and 2 – with exception on the surface area, which was measured using GIS data produced by Jeddah Municipality.

[illegible]

PLANT WATER USE		
Plant Type	Percent Range	
	High	Low
Low Water Use	0.26	0.13
Medium Water Use	0.45	0.26
High Water Use	0.64	0.45

Table 2 Plant water use factor (Source Bickelmann, 2006, *Harvesting Rain Water For Landscape Use*, 24)

MONTH	POTENTIAL EVAPORATION - ET _o	
	mm	Inch
Jan	8.3	0.32
Feb	10	0.4
Mar	10.7	0.42
Apr	12	0.47
May	12.5	0.49
Jun	12.6	0.49
Jul	12.8	0.5
Aug	13.1	0.51
Sep	12.5	0.49
Oct	10.8	0.42
Nov	9.8	0.38
Dec	7.9	0.31

Table 3 Evapotranspiration ETo data (Source Ricks, 1992, *Landscape Plant Manual for Saudi Arabia*)

4.2 Data Calculations

Model 1: The potential rainwater harvesting volume (Supply) was estimated by using the following equation (1):

$$(1) \quad VR \text{ (in Gallons)} = P(\text{inches}) \times \text{Area (ft}^2) \times C \times 0.623$$

Where P is the average annual rainfall that falls in Jeddah City. The parameter C is a runoff coefficient based on the Rational Method (see Table 4). The conversion factor 0.623 is used to measure the supply in US gallons. Table 5 shows the calculation and Figure 20 demonstrates the outcome for Model 1.

RUNOFF COEFFICIENTS		
Land Use Type	High	Low
Roof		
(A) Metal, asphalt, shingle, fiber glass	0.95	0.9
Paving		
(B) Concrete, asphalt	1	0.9
(C) Gravel	0.7	0.25
Soil		
(D) Flat, Bare	0.75	0.2
(E) Flat, with vegetation	0.6	0.1
Lawns		
(F) Flat, sandy soil	0.1	0.05
(G) Flat, heavy soil	0.17	0.13

Table 4 Values of runoff coefficient (C) (Source: Bickelmann, 2006, *Harvesting Rain Water For Landscape Use*, 14)

	Rainfall in/m	Gallons	Catchment surface sq.ft	Gallon of rainfall /m	Runoff Coefficient							Total Monthly RWH in Gallons						
					A	B	C	D	E	F	G	A	B	C	D	E	F	G
Jan	0.42	0.26166	1000	261.66	0.95	1	0.7	0.75	0.6	0.1	0.17	248.577	261.66	183.162	196.24	156.99	26.16	44.48
Feb	0.12	0.07476	1000	74.76	0.95	1	0.7	0.75	0.6	0.1	0.17	71.022	74.76	52.332	56.07	44.85	7.47	12.70
Mar	0.09	0.05607	1000	56.07	0.95	1	0.7	0.75	0.6	0.1	0.17	53.2665	56.07	39.249	42.05	33.64	5.60	9.53
Apr	0.09	0.05607	1000	56.07	0.95	1	0.7	0.75	0.6	0.1	0.17	53.2665	56.07	39.249	42.05	33.64	5.60	9.53
May	0.007	0.004361	1000	4.361	0.95	1	0.7	0.75	0.6	0.1	0.17	4.14295	4.361	3.0527	3.27	2.61	0.43	0.74
Jun	0	0	1000	0	0.95	1	0.7	0.75	0.6	0.1	0.17	0	0	0	0	0	0	0
Jul	0.007	0.004361	1000	4.361	0.95	1	0.7	0.75	0.6	0.1	0.17	4.14295	4.361	3.0527	3.27	2.61	0.43	0.74
Aug	0.01	0.00623	1000	6.23	0.95	1	0.7	0.75	0.6	0.1	0.17	5.9185	6.23	4.361	4.67	3.73	0.62	1.05
Sep	0.003	0.001869	1000	1.869	0.95	1	0.7	0.75	0.6	0.1	0.17	1.77555	1.869	1.3083	1.40	1.121	0.18	0.31
Oct	0.03	0.01869	1000	18.69	0.95	1	0.7	0.75	0.6	0.1	0.17	17.7555	18.69	13.083	14.01	11.21	1.86	3.17
Nov	0.87	0.54201	1000	542.01	0.95	1	0.7	0.75	0.6	0.1	0.17	514.9095	542.01	379.407	406.50	325.20	54.20	92.14
Dec	0.43	0.26789	1000	267.89	0.95	1	0.7	0.75	0.6	0.1	0.17	254.4955	267.89	187.523	200.91	160.73	26.78	45.54
Totals	2.077			1293.97								1229.2725	1293.971	905.7797	970.47	776.38	129.39	219.97

Table 5 Monthly water supply worksheet – Model 1 (Source: Author)

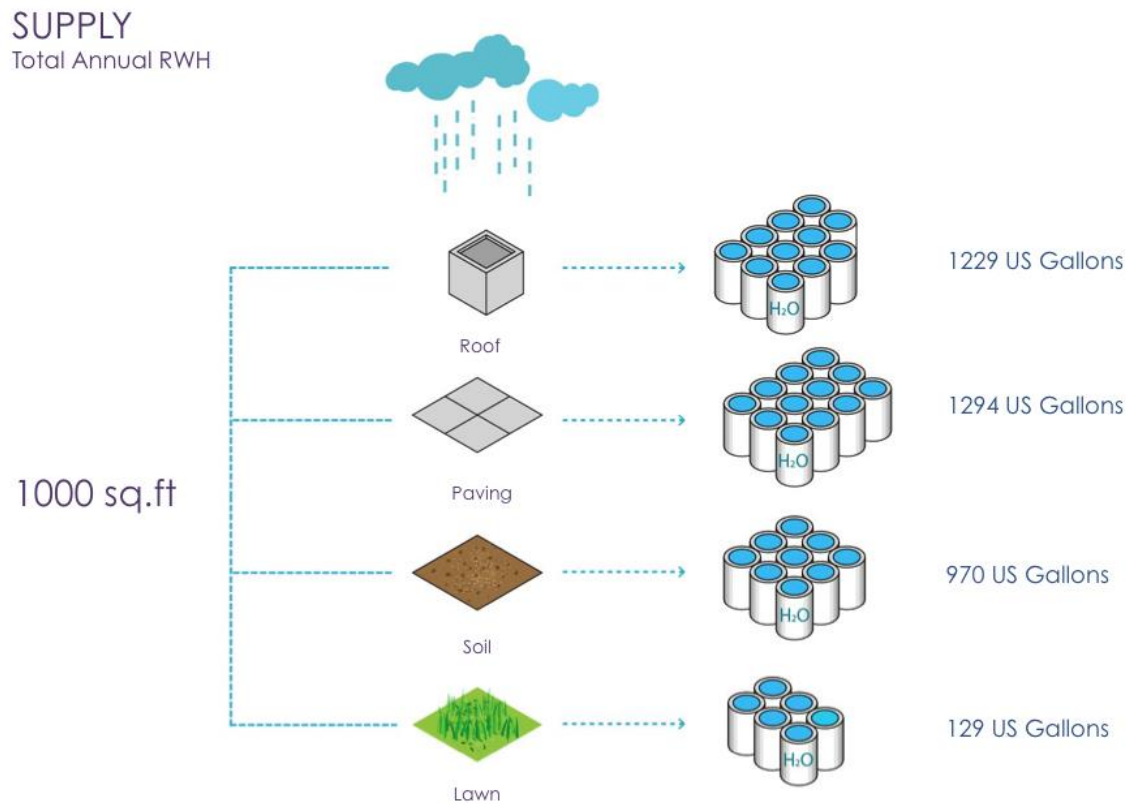


Figure 20 Diagram demonstrating the outcome of Model 1 (Source: Author)

Model 2: The Water requirement for landscape irrigation was estimated using the following equation (2):

$$(2) \quad WR \text{ (in Gallons)} = ET_o \times Pf \times LA \text{ (ft}^2\text{)} \times 0.623$$

Where ET_o is monthly evapotranspiration (refer to Table 2) and Pf is the Plant water use factor and LA is the landscape surface area in square feet. The conversion factor 0.623 is used to measure the water demand in US gallons. Table 6 shows the calculation and Figure 21 demonstrates the outcome for Model 2.

	monthly evapotranspiration (ET_o)	Plant Factor			Water needs in inches			Water needs in gallons per sq.ft			Total landscape area sq.ft	Total water demand in gallons		
		Low	Medium	High	Low	Medium	High	Low	Medium	High		Low	Medium	High
Jan	0.32	0.13	0.26	0.45	0.04	0.08	0.14	0.02	0.05	0.08	1000	25.91	51.83	89.71
Feb	0.4	0.13	0.26	0.45	0.05	0.10	0.18	0.03	0.06	0.11	1000	32.39	64.79	112.14
Mar	0.42	0.13	0.26	0.45	0.05	0.10	0.18	0.03	0.06	0.11	1000	34.01	68.03	117.74
Apr	0.47	0.13	0.26	0.45	0.06	0.12	0.21	0.03	0.07	0.13	1000	38.06	76.13	131.76
May	0.49	0.13	0.26	0.45	0.06	0.12	0.22	0.03	0.07	0.13	1000	39.68	79.37	137.37
Jun	0.49	0.13	0.26	0.45	0.06	0.12	0.22	0.03	0.07	0.13	1000	39.68	79.37	137.37
Jul	0.5	0.13	0.26	0.45	0.06	0.13	0.22	0.04	0.08	0.14	1000	40.49	80.99	140.17
Aug	0.51	0.13	0.26	0.45	0.06	0.13	0.22	0.04	0.08	0.14	1000	41.30	82.60	142.97
Sep	0.49	0.13	0.26	0.45	0.06	0.12	0.22	0.03	0.07	0.13	1000	39.68	79.37	137.37
Oct	0.42	0.13	0.26	0.45	0.05	0.10	0.18	0.03	0.06	0.11	1000	34.01	68.03	117.74
Nov	0.38	0.13	0.26	0.45	0.04	0.09	0.17	0.03	0.06	0.10	1000	30.77	61.55	106.53
Dec	0.31	0.13	0.26	0.45	0.04	0.08	0.13	0.02	0.05	0.08	1000	25.10	50.21	86.90

Table 6 Monthly water demand worksheet for landscape area - Model 2 (Source: Author)

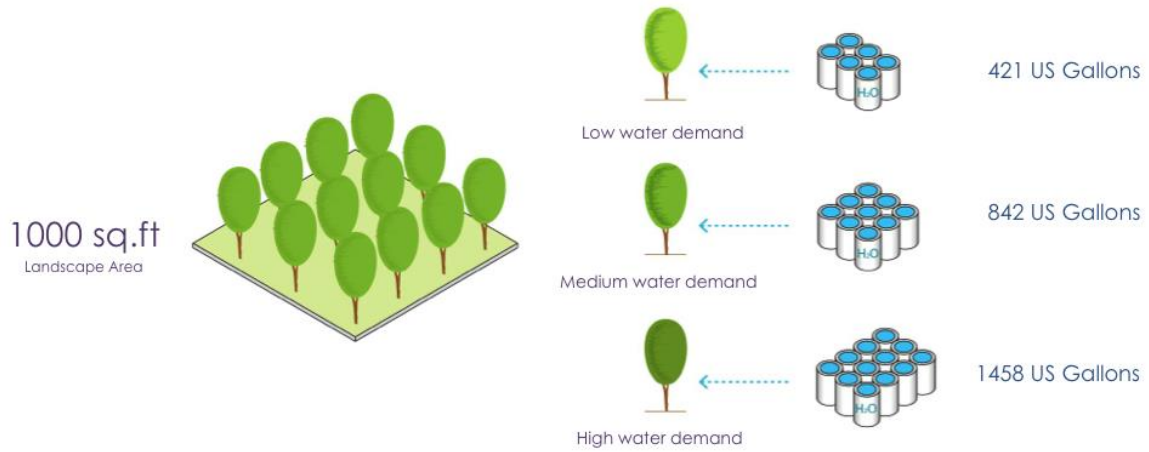


Figure 21 Diagram demonstrating the outcome of Model 2 (Source: Author)

Model 3: The potential supply and demand of rainwater in the study area (historical city of Jeddah) was estimated using equation 1 and 2 (see Figure 22):

$$(1) \quad VR \text{ (in Gallons)} = P(\text{inches}) \times \text{Area (ft}^2) \times C \times 0.623 \text{ (Supply)}$$

$$(2) \quad WR \text{ (in Gallons)} = ET_o \times Pf \times LA \text{ (ft}^2) \times 0.623 \text{ (Demand)}$$

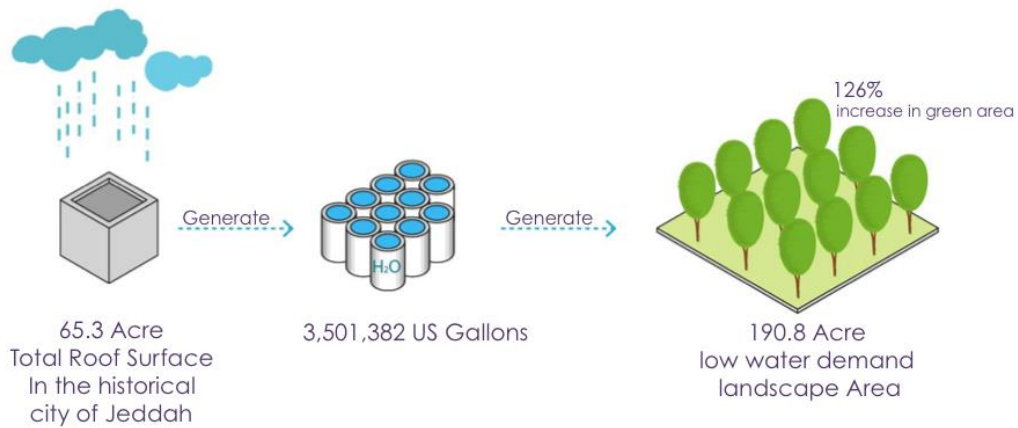


Figure 22 Diagram demonstrating the outcome of Model 3 (Source: Author)

4.3 Results and Discussion

The result of the study shows that Jeddah has on average 53.5 mm (2.1 in) of rainfall per year, or 4.5 mm (0.2 in) per month. The driest weather is from May to September when an average of 0-0.2 mm of rainfall (precipitation) occurs. The wettest weather is in January, November, and December. In addition, the study demonstrates that there is substantial potential to capture and use rainwater for landscape use in the study area. The total rooftop area in the study area is equal to 65.3 acres and is capable of capturing around 3.5 million gallons of rainwater per year. This amount of water would be enough to generate 191 acres of landscape area. This scenario assumes that rooftop rainfall at the study area will use only captured-water for landscape irrigation. However, as discussed in Chapter 3, captured rainwater can be used for different purposes, including domestic drinking water and non-potable use like toilet flushing. Since Jeddah residents were already using RWH as a traditional adaptation to living in a very arid environment, many buildings in the historical city have underground cisterns that were originally built to store the rainwater captured from the rooftop. Unfortunately, most of these cisterns are not used for RWH anymore, although they could be revived and put back into use. A detailed feasibility plan for urban rainwater harvesting is required to develop a sustainable water management plan that addresses the future water demand. This would include an assessment of legal, technical, and economic barriers to implementing a new RWH system as well as revitalizing the traditional RWH system in Jeddah City.

CHAPTER 5

SUSTAINABLE WATER MANAGEMENT STRATEGIES

In this chapter, I provide an urban analysis of the historical and modern city of Jeddah. I suggest design strategies specific for each of the five zones of the urban transect. In this way, I propose two phases for sustainable water management strategies based on traditional knowledge, best management practices, and green infrastructure for rainwater and storm water management.

5.1 History of Conservation and Development Strategies for the City of Jeddah

The historical city of Jeddah is a unique, outstanding example of an Islamic urban center on the coast of the Red Sea. The site represents a major stage in the human settlement of the Red Sea area because its strategic maritime location helped promote the city as the dominant center of a commerce network connecting African, Arabian, and Indian cities. The site is the best-preserved example of the traditional Red Sea urban and architectural style in the Kingdom of Saudi Arabia as well as beyond its national borders. Located in the heart of the modern city of Jeddah and covering over a surface of 65 hectares, the extraordinary urban fabric of the city with its marvelous houses built of coral, souks, and vernacular plazas and open spaces offers a stunning image of the exceptional Hijazi architectural style during the 19th century (see Figure 23).⁹⁸

Throughout its history, Jeddah developed as an important commercial center and, especially since the 7th century, as a major harbor for the holy pilgrimage city of Makkah. Muslim pilgrims from Africa and Asia coming by sea used to land in Jeddah before

travelling on to the Holy City of Makkah. As a result of these visitors, some of whom eventually settled there, the city became a melting pot of diverse cultural heritage traditions.⁹⁹



Figure 23 Map showing the location of the historical city of Jeddah (Source: Jeddah Municipality, 2013, Jeddah Strategic Plan, Introduction, 16. Google Earth 2013. Jeddah)

But the traditional city underwent enormous changes in the 20th century. It experienced a massive unprecedented development following the oil boom in 1938 along with the connecting of the city to a new water supply system and the demolishing the city wall in 1947. During the following three decades, large parts of Jeddah's historical urban fabric were removed or transformed.¹⁰⁰ A new road was constructed through the old city in the 1970s, separating the old city into two sections (east and west). Large portions of the western part of the city were partially redeveloped. The city coastline was reclaimed and transformed by modern developments, disconnecting the city from the sea. With an increasing difference between traditional and modern ways of living, residents abandoned their old houses and moved outside the old city to resettle in new houses in modern Jeddah. Meanwhile, the old houses were rented to poor immigrant tenants who could not

properly maintain the properties, leading to a severe deterioration (see Figure 24).¹⁰¹

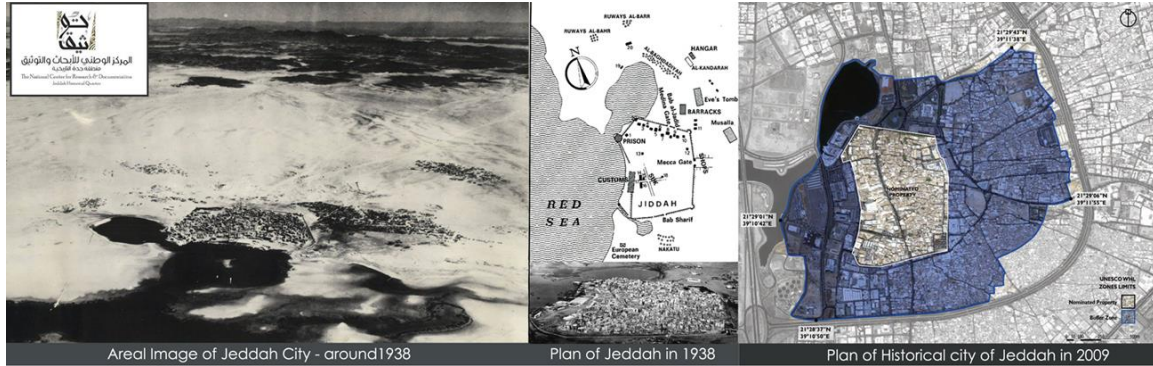


Figure 24 Collage representing Jeddah City in 1938 and 2009 (Source: The National Center for Research and Documentation and the UNESCO nomination document for the historical city of Jeddah)

However, the Mayor of Jeddah, Muhammad Sa'id Farsi (who served as mayor from 1972-1986), realized the importance of the cultural heritage value of old Jeddah and decided to save it from total destruction.¹⁰² In 1980, Farsi hired a British consulting firm under the supervision of Robert Matthew to make the first detailed survey map of houses in the old city and create a master plan for the preservation of the historic areas. Matthew's team was able to survey and classify all the houses in the historical area based on the architectural style and the historical significance of the building. This was followed by a conservation plan in 1982 for old Jeddah with a vision to maintain the city's original role as a residential and commercial center while upgrading the urban environment.¹⁰³ Modern conveniences such as electricity, piped-in water, and sewage removal were connected to all the houses. Streets and alleyways were covered with marble, granite, and basalt slabs. The Municipality of Jeddah City also proposed new public areas and street furniture including, benches, lamppost, tree boxes, and fountains in the historical area.

Because this plan proposed improvements that, for the most part, did not damage the existing traditional fabric, it significantly slowed down the new development of the

area and saved the city from total destruction. However, there were multiple stakeholders and complex ownership issues related to Islamic inheritance law (which is extraordinarily complex) and other legal issues that affected the conservation plan. As a result, the conservation planning relegated itself primarily to beautification of the archaeological heritage to enhance the image of the old city.¹⁰⁴

In 2006, the Supreme Commission for Tourism submitted an application to the United Nations Educational, Scientific, and Cultural Organization (UNESCO) for World Heritage Site status for the historical city of Jeddah. The application was included in the tentative list by UNESCO, but as of 2013 has still not been inscribed as a World Heritage site. Unfortunately, today the historical city is facing severe deterioration. It is struggling to survive under the threat of new development, degradation of historic sites, drastic social and economic changes, natural disasters, and loss of collective memory and identity. As a result, it was listed on the ICOMOS World Report 2008-2010 as one of the monuments and sites in danger.

In 2010, the Saudi Commission for Tourism and Antiquities prepared the nomination document for the Historical City of Jeddah inscription on the UNESCO world heritage list. The document includes comprehensive conservation and development strategies with technical guidelines for protection of the cultural heritage of the city. In addition, it aims to promote the social and economic development of the historic city center. The nomination document also addresses most of the current environmental issues of the site, including water scarcity and environmental degradation caused by climate change, urbanization, and population growth. However, in attempting to address these,

the Commission failed to provide sustainable solutions that could improve conditions for both the old and new city.

5.2 Urban Analysis

The city of Jeddah consists of two major parts, the historical core and the new city, and these are connected and, to some degree, interdependent. In my design analysis, I draw an east-west urban transect that begins from the historical core and continues to the new city in order to analyze the urban fabric in and between them both and ultimately to develop urban water design strategies for both the historical and the new city (see Figures 25 and 26). The urban transect is divided into five zones: A and B represent the historical city, C and D represent the new city, and finally E represents the natural zone. These zones are subdivided on the basis of the major development and preservation phases that shaped the current urban form of old Jeddah and the new city next to it.

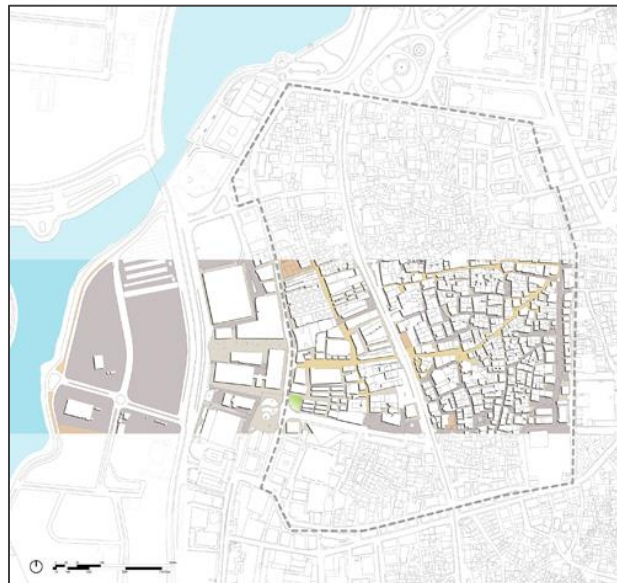


Figure 25 Urban transect (Source: Author)

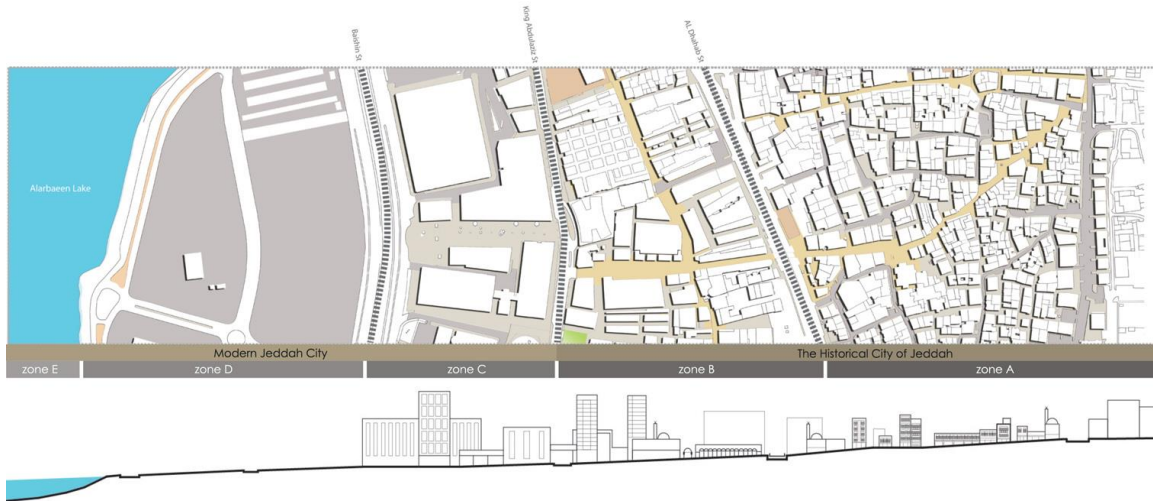


Figure 26 Urban transect zoning (Source: Author)

Zone A, the eastern side of the historical city of Jeddah, contains around 70% of the original fabric of the historical city. This zone is characterized by narrow pedestrian-scale streets, beautiful coral houses, historic souks (markets), plazas and squares, and dead-end impasses. The dominant land use is traditionally residential. It is also comprised of resourceful groups of mixed commercial, religious, and governmental properties. In addition, this part of the city contains the majority of the designated historic properties. Many of these historic houses, such as Nasif House, have a traditional rainwater harvesting system that was designed to capture rainwater from rooftop (see Figure 3).

The development phase that occurred between the 1960s and 1970s disturbed the original fabric in some areas in this zone. Among the old historical buildings, the modern buildings stand out. All the roads were paved, allowing automobiles to access the site, but the streets had not been designed for vehicular traffic, and thus this had a detrimental effect. Those vehicles require parking and, with limited space, the citizens began parking in any available open space. As a result, many historical squares were transformed into parking lots. Moreover, the exhaust from automobiles squeezing into crowded, narrow

roads negatively affected the air quality. This also disturbed the natural ventilations – one of the main components of traditional sustainability of the city (see Figures 27 and 28).



Figure 27 A view represent the urban condition in Zone A (Source: the UNESCO nomination document for the historical city of Jeddah)



Figure 28 View of the eastern part of the historical city - Zone A (Source of the image: Jeddah Municipality. 2013. Jeddah Strategic Plan, Introduction)

Zone B, the western side of the historical city, plays an important role in the historical time frame for the city. It symbolizes the conflict between preserving the old

city as a place where people actually live comfortably and the desire for modern lifestyles that residents experienced in the 1960s-1970s. This part of the city was significantly redeveloped. Most of the traditional buildings were demolished and replaced by mixed-use modern buildings (typically high-rises of brick, cement, and glass). Today, this area contains a mixture of modern buildings and infrastructure merged within a few surviving clusters of traditional urban fabric, including a number of traditional Red Sea houses, designated historic properties, and historic souks (see Figure 29).



Figure 29 Collage represent the changes in Zone B, example of souk Qabil (Source of the images: The National Center for Research and Documentation at Jeddah. Historic image of Souk Qabil. Personal photography. Souk Qabil 2013)

Zones C and D are the outcome of a land reclamation project by the Jeddah Municipality in the 1970s. The original seashore has been reclaimed through landfill and changed by modern developments, disconnecting the old city from the sea. The majority of land in Zone C is commercial and includes office buildings, hotels, indoor shopping malls, and commercial pedestrian corridors – most of which were built in the 1970s-1980s. Zone D is mostly empty land, except a massive parking lot and some industrial facilities, including a wastewater treatment plant, situated on the southern side. The city is planning to develop this zone in the future as a mixed-use development area that contains retail, recreational facilities, residential, hospitality use, offices, and multi-story parking (see Figure 30).

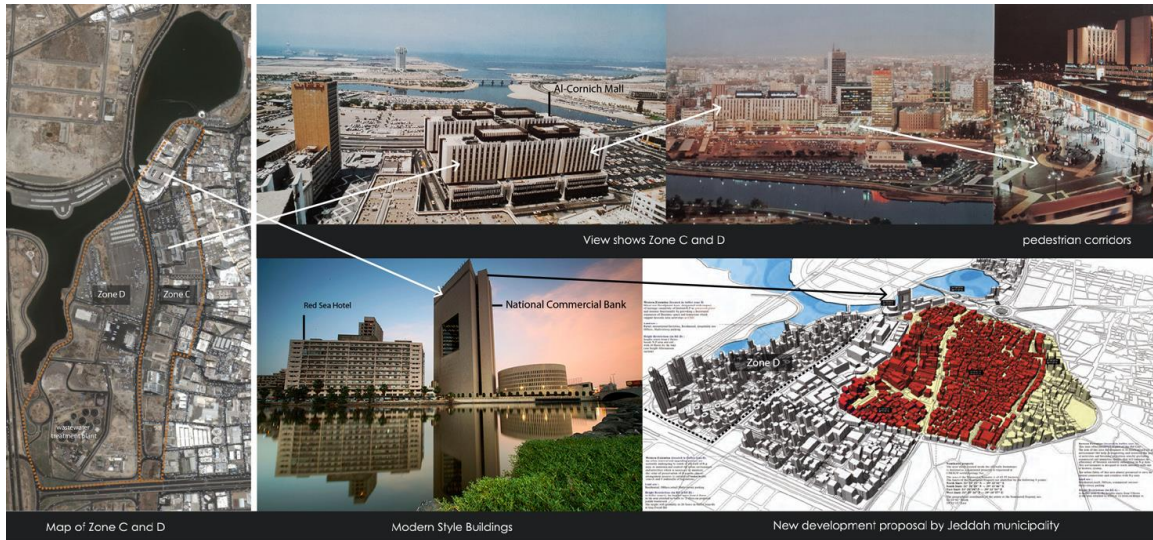


Figure 30 Collage representing Zone C and D (Source of the images: Jamal Azhar, 1996, *Jeddah the gateway of the two holy mosques*. UNESCO nomination document for the historical city of Jeddah. Dany Eid (photographer), 2013, Jeddah Skyline. Retrieved Jan 10 2014, from: www.flickr.com/photos/eiddany/8760200066/)

Zone E represents the natural zone, which in our site is the Alarbaen Lagoon linked to the Red Sea. The land reclamation project in the 1970s, coupled with the new infrastructure, significantly affected the shape and the water quality of the lagoon. Historically, people used this area for recreational purposes that included swimming, fishing, and boating. In addition, they extracted mud from the lagoon and used it along with other natural local materials such as coral stones to build traditional houses. Unfortunately, for decades, the city allowed the wastewater to be discharged into the lagoon, leading to severe water pollution and environmental degradation. Later, the city began a cleaning project to improve the water quality in the lagoon, but the recovery process will take time.

The data and analysis collected cover all five zones. A site inventory including land use, buildings style, historic buildings classification, public spaces, and street network are defined using GIS data, satellite images and reports provided by Jeddah Municipality (see Figure 31 and 32).

Landuse

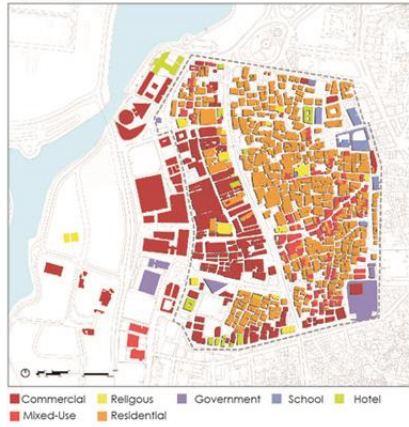
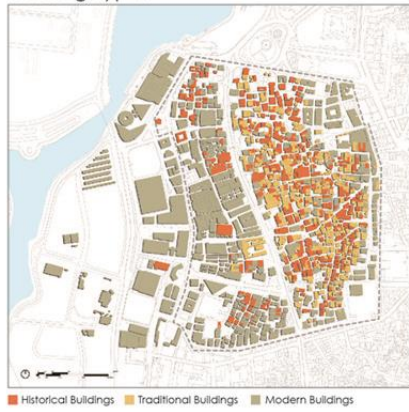


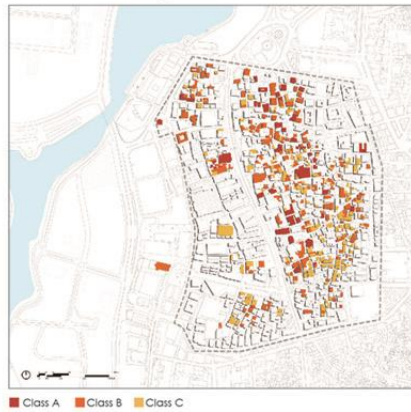
Figure Ground



Building Types



Historic Building Classification



Streets +Parking lots



Pedestrian walkways+ Souks



Figure 31 Urban mapping for the historical city of Jeddah (Data Obtained from Jeddah Municipality)

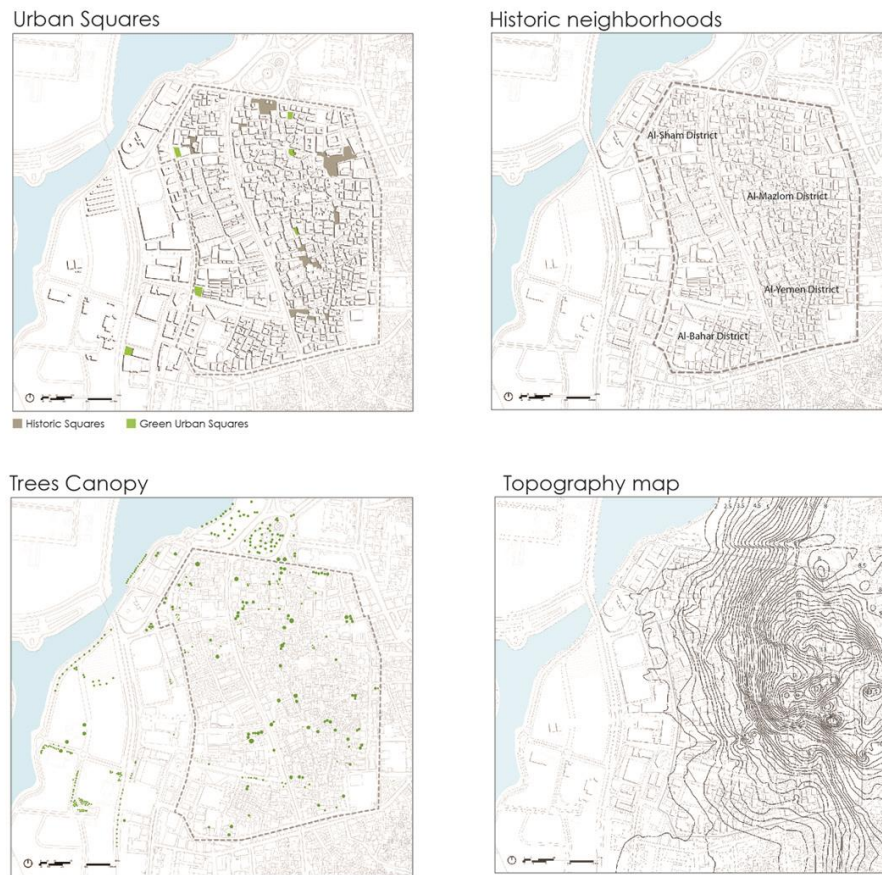


Figure 32 Additional urban mapping for the historical city of Jeddah (Data Obtained from Jeddah Municipality)

5.3 Design Strategies

The sustainable water management strategies that I proposed for Jeddah City and its historical core are based on traditional knowledge (as discussed in Chapter 2) as well as the best management practices and green infrastructure for rainwater and storm water management (as discussed in Chapters 3 and 4). The design strategies are comprised of two main phases. The first phase proposes strategies for the water scarcity problem and environmental degradation on the historical-city scale. The second phase utilizes the urban transect to manage different water strategies at a smaller scale for buildings,

streets, and parking lots in each zone.

In phase one, to address the current water shortage, I propose central rainwater storages for Zones A, B, C, and D at the neighborhood level that will collect and preserve rainwater from surrounding roofs and from the occasional overflow from existing underground cisterns. The sites for these storages are public lands such as urban squares, gardens, and parking lots – a selection based on the land use availability and the potential coverage area. In addition, I propose a green network that includes green streets, public gardens, and a wetland park to control storm water runoff and to improve environmental quality, public health, and enhance the image of the city (see Figures 33 and 34).



Figure 33 Proposed green network (Source: Author)



Figure 34 Maps show the storm water flow and the proposed central rainwater storage (Source: Author)

In phase two, I focus on three common urban typologies—namely buildings, streets, and parking lots—in the study area for which I have developed a set of strategies that is mainly derived from the traditional practices of rainwater harvesting and the best management practices (BMP), with consideration to the specific site requirement in each zone.

5.3.1 Building Strategies

There are three types of buildings in the study area:

- 1- Designated historical Red Sea buildings.
- 2- Traditional Red Sea buildings.
- 3- Modern buildings

The designated historical Red Sea buildings are located only in Zones A and B with an exception of one building located in Zone C (see Figure 31, “Historical Building Classification”). Based on the historical data, I categorized these building into two types – those with traditional rainwater harvesting system and those without rainwater

harvesting system. The proposed design strategies include the restoration of the existing rainwater harvesting systems, including rooftop surface collection, pipes, and the underground cistern. For historic buildings without underground cisterns, I recommend the use of rain barrels where feasible. The collected water will be used for non-potable domestic use and landscape irrigation. For potable use, a good purification system is needed to accompany the distribution system. In heavy rain events, the overflow from underground cisterns or rain barrels will be directed to the proposed central storage tanks mentioned in phase one (see Figure 34). It is important to highlight that, before implementing any design strategy, the condition of the historic buildings and rainwater harvesting systems must be evaluated to ensure water quality and building stability. The historic building codes and water supply company regulations should be followed to avoid cross-connection. In addition, preserving the integrity and authenticity of the historic building should be prioritized.

Traditional Red Sea buildings are also located in Zones A and B (see Figure 31, “Building Types”). The majority of traditional buildings do not have an underground cistern. Their roof surfaces are flat and sloped, allowing rainwater to be directed outward through a hollow wooden waterspout. The strategies I propose for these buildings include connecting the existing downspout system to a sufficient number of rain barrels with filtration to ensure water quality. In major rain events, the overflow water will be directed to planter boxes and then to the suggested central storage tank.

Modern buildings, mostly built during the 1970s-1980s, dominate in Zones A, B, C, and D (see Figure 31, “Buildings Types”). Instead of rainwater-harvesting systems, these buildings direct the rainwater away through downspout system to the sewer system

(similar to the traditional buildings). Nevertheless, those buildings offer an opportunity for green retrofitting and renovation interventions that includes green roofs, blue roofs, green walls, downspouts, above ground cisterns, and rain barrels. I propose these systems taking into consideration the historical and cultural heritage integrity of the location of those buildings. For future development particularly in Zone D, I recommend applying sustainable building strategies that combine both traditional forms of sustainability used in Jeddah city and contemporary green buildings strategies (see Figures 35 and 36).



Figure 35 Building strategies matrix (Source: Author)

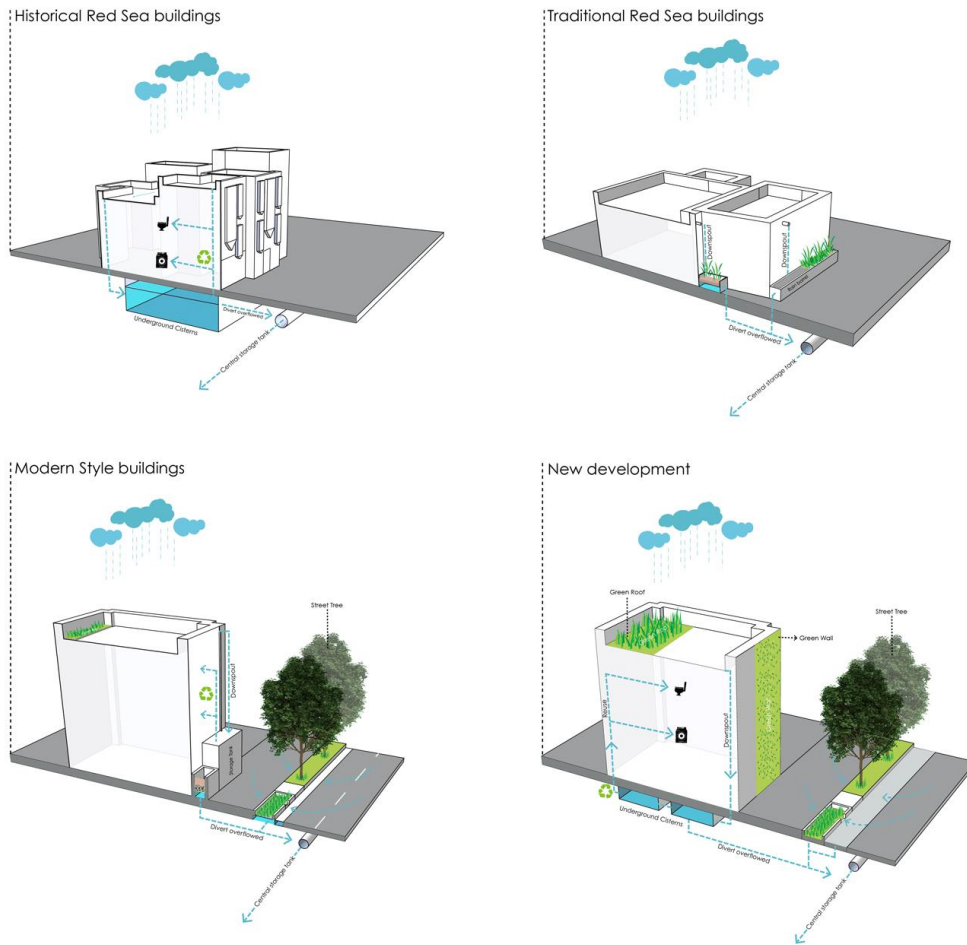


Figure 36 Diagrams demonstrating the proposed building strategies (Source: Author)

5.3.2 Street Strategies

After significant rainfalls, streets generate storm water runoff that is currently causing a wide range of environmental issues, such as water pollution. Nevertheless, based on the literature review in Chapter 3, we know that streets offer a great opportunity for green street solutions. However, we have to be conscious of that fact that there are two different kinds of street typologies; the street typology of the historical city is different from the streets in the modern section of the city. Streets in the new city can be generally classified into freeways, arterials, toll roads, local roads, and pedestrian streets

(see Figures 37 and 38). In the historical area and its surrounding buffers, I have identified four dominant types of streets based on their functions:

- 1- Primary local streets
- 2- Commercial streets
- 3- Residential streets
- 4- Pedestrian streets
 - a. Commercial pedestrian streets (Souks) that are categorized into covered and open-air streets
 - b. Neighborhood alleyways

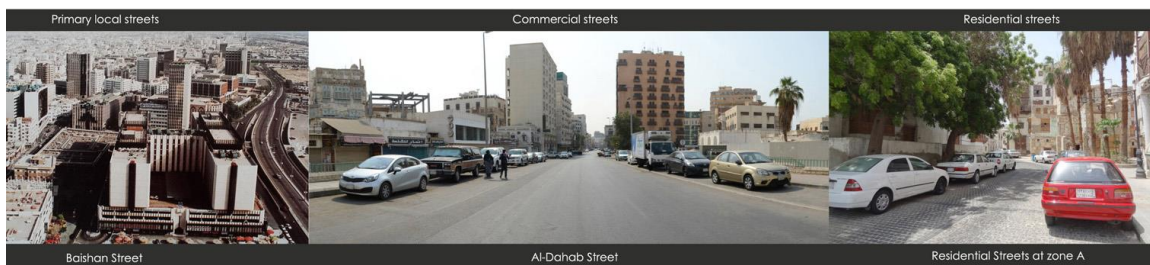


Figure 37 Examples for local, commercial, and residential streets (Source from left to right: Jamal Azhar, 1996, *Jeddah the gateway of the two holy mosques*. Abdulelah Matsah (Landscape architect), 2013. King Abdulaziz University)

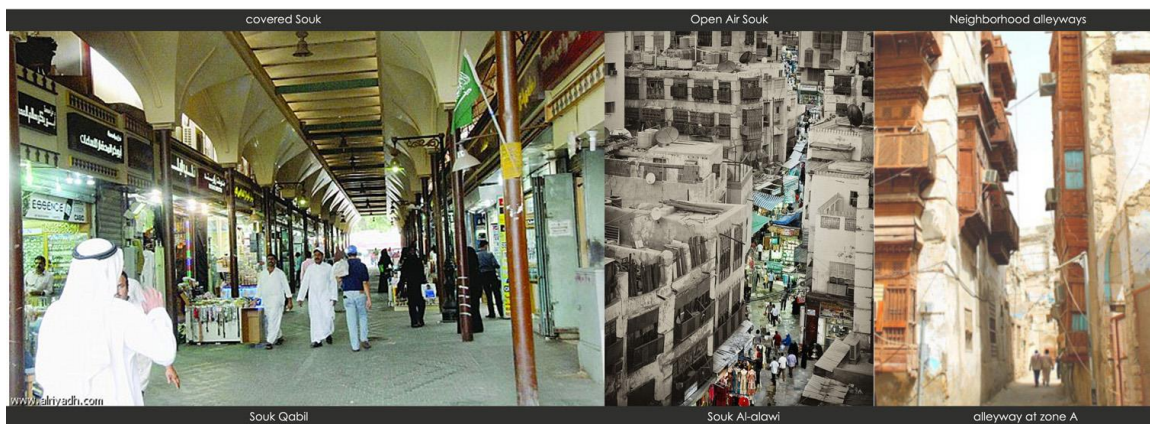


Figure 38 Examples for pedestrian streets (Source from left to right: Alriyadh Online News, 2012, Qabil Street. Retrieved April 11 2014, from: <http://www.alriyadh.com/702260>. Conservation Society of Architecture Heritage in Jeddah-Database)

In the historic area, primary local streets, such as Baishan Street, are wide, high-volume streets, designed to serve vehicles with little emphasis on walkability. They have

a central median strip that, in many areas, is vegetated. During rain events, and especially the extreme downpours, these types of streets produce significant amounts of storm water runoff and they often flood due to overloading of the current grey discharge system. I proposed to redesign the primary local streets by introducing green street strategies that will help to slow the conveyance of storm water runoff and provide a wide range of environmental benefits. The proposed green street strategies include bioswales, planters-curb extensions, and permeable pavements (see Figure 39).



Figure 39 Section detail demonstrating the design strategies for primary Local Street (Source: Author)

Commercial streets in the historical city are one-way streets and are considered high-density streets both in terms of pedestrian and vehicle movement. They have sidewalks on both sides and on street parking in some parts. Al-Dahab Street is one of the commercial thoroughfares in the historical city that was constructed in the 1970s, dividing the historical city into two parts (see Figure 37). The strategies that I proposed for Al-Dahab Street promote connectivity through transforming the street into a green, mixed-use commercial street where pedestrians feel more welcome and safe. This shift

will allow people to move safely between the eastern and western side of the historical city. One way to generate space for green intervention in these types of streets is to convert the current angled parking to parallel parking. This will provide more space for wider walkways, bike lanes, and landscape space for storm water management (see Figure 40).

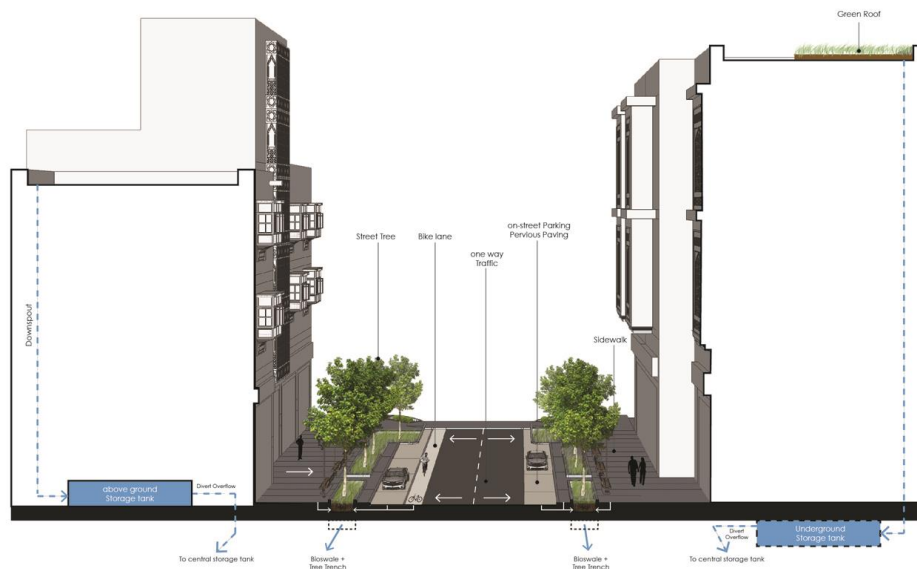


Figure 40 Section detail demonstrating the design strategies for commercial streets (Source: Author)

Residential streets in the historical area and particularly in Zone A are typically narrow, one-way, and also high-density during the morning time. Considering the space restriction, I recommend using pervious paving in some areas, which will be connected to outfall pipes that direct storm water to nearby proposed green streets or landscape areas. In addition, in some areas where residential streets are wider and have sidewalks, I recommend using planter or/and tree boxes to absorb some of the excess water (see Figure 41).



Figure 41 Section detail demonstrate the design strategies for residential streets (Source: Author)

Commercial pedestrian streets, also known as souks, are one of the most vibrant places in the historical city of Jeddah. Local people regularly visit old Jeddah for shopping in its historic and modern souks, which are well known for their good quality and low prices. Historically, souks were organized according to the goods sold there, for example, the spice market, the fabric market, etc. However, for the purpose of this research, I have categorized the souks into three formal types. The first type is the covered souk such as Souk Al-Nada, located in Zone B. The second type is the liner, open-air souk such as the west side of Souk Qabil that is also located in Zone B. The third type is the open-air souks with squares such as Souk Al-Alawi, located in Zone A (see Figure 38). The design strategy that I recommend for covered souks is to collect rain from the covered surface and store it in a sufficient number of rain barrels. The overflow will be directed to nearby green streets. Most of the liner open-air souks are wide; thus

they offer an easy opportunity for green intervention. With respect to the historic value of these areas, I suggested the use of planters, tree boxes, and pervious paving whenever it is applicable to manage storm water.

Squares within the souk are located near important buildings such as mosques and they connect spaces within the souk and provide areas for social interaction and rest. These squares offer a great chance to apply soft solutions that not only will manage storm water, but will also improve environmental quality and the social life. Neighborhood alleyways in the historical area have similar green intervention opportunities and constraints, like the other pedestrian streets. Most of the alleyways in Zone A and B are narrow and shaded by the surrounding tall buildings. I propose using pervious paving with outfall pipes that directs storm water to nearby proposed green streets (see Figure 42).



Figure 42 Section detail demonstrating the design strategies for neighborhood alleyway (Source: Author)

5.3.3 Parking Lot Strategies

Parking lot sizes and shapes differ from site to site in the historical area and its surroundings. Currently, there are many small and large parking lots in the study area; however, most of these parking areas are not designed with GI in mind. Thus, there is an opportunity to adapt these parking lots to include all or some of the following: vegetated swale, storm water planter, pervious pavers, green gutters, rain gardens, and underground detention-retention tanks (see Figures 43 and 44). It is important to mention that Jeddah Municipality is planning to limit the access of private vehicles to the historic area and promote public transportation instead. As a result, many existing parking lots will be transformed to mixed-use development and in their place I assume that new parking lots outside the historical area will be created. I believe this shift will improve the overall environmental quality, and in particular the air quality in the historical area. Also it will promote safe walkability. A combined matrix of the strategies I have suggested for streets and parking lots is presented in Figure 45.



Figure 43 Section detail demonstrating the design strategies for residential parking lot (Source: Author)

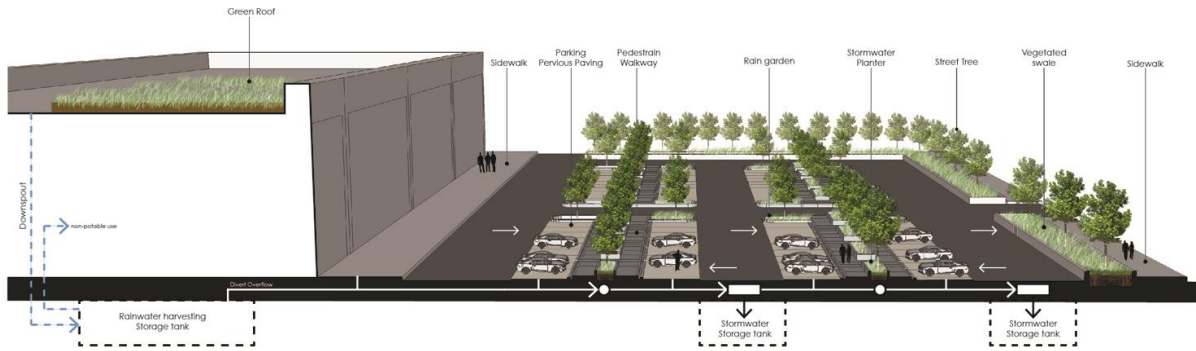


Figure 44 Section detail demonstrating the design strategies for commercial parking lot (Source: Author)

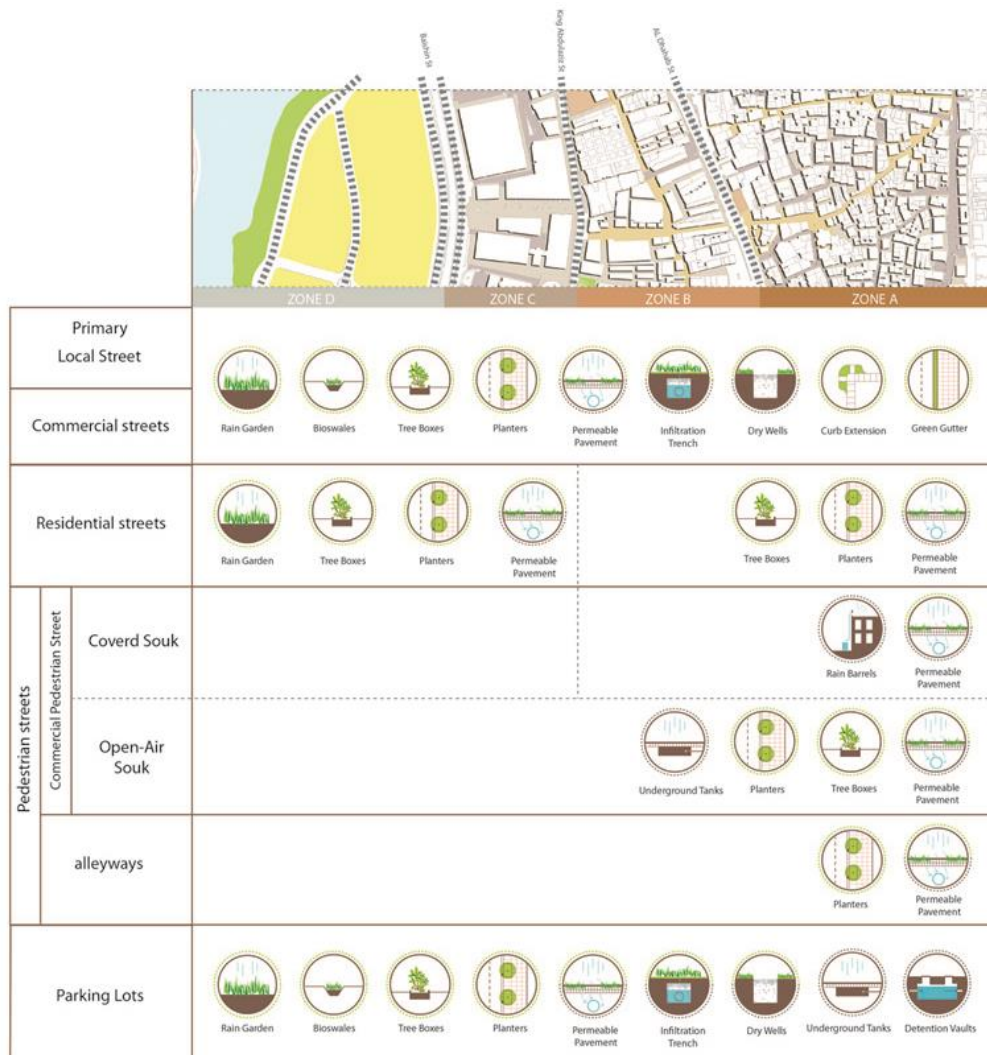


Figure 45 Street and parking lot strategies matrix (Source: Author)

CHAPTER 6

CONCLUSION

The traditional practice of rainwater collecting and harvesting is a strategy that was historically used to address both excessive aridity and excessive water during flood events. Unfortunately, these traditional practices were abandoned in many areas in MENA regions including Jeddah City, Saudi Arabia. In the 21st century, many methods and strategies for storm water management were or are still being developed, including green infrastructure, best management practices, and low impact development. All these new strategies are based on the same principals of traditional rainwater harvesting that are grounded on natural processes and proven to provide a wide range of environmental, social, and cultural benefits.

Considering the global issue of climate change, water shortage and degradation of urban environment in the Middle East and North Africa (MENA), this thesis proposed sustainable urban water management strategies for arid regions using both traditional and modern practice of rainwater harvesting and storm water management. This research focused specifically on the context of Jeddah City and its historical core, but it also presents possible solutions for coastal urban areas in the MENA region and particularly for those locations experiencing rapid population, urbanization, and tourism growth while at the same time suffering from both the water shortage and excessive water. The main objective of these proposed strategies are to provide water recourse for drinking and irrigations, minimize the consumption of non-renewable natural resources, diminish urban run off by using soft infrastructure solutions (such as green infrastructure,) and to improve the environmental quality and social life for the growing population.

In Jeddah City, green infrastructure can be promoted as a modern version of the traditional rainwater harvesting practice that Jeddah City used for centuries to deal with its water related problems. The result of this research indicates that green infrastructure can be retrofitted to the current urban fabric and it proposes that green practices for rainwater harvesting and storm water management should become part of future planning, development, and redevelopment of the city. To achieve this, Jeddah Municipality need to establish the technical support including design strategies and guidelines that would help developers, communities, and individuals design and apply green storm water management systems.

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